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THE METALLURGY OF TITANIUM.*

BY

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I. INTRODUCTION.

So far as has come to the attention of the writer, there has never been any systematic attempt to set forth a metallurgy of titanium, or, for that matter, to take cognizance of the fact that the element possesses an extremely interesting and somewhat complicated metallurgy. If volume of scattered literature is any criterion, the importance of titanium, long recognized as a rare element, has assumed such proportions that it would seem consistent and harmonious with modern ideas if the principal writings were collated. The service that titanium in the form of a ferro-alloy renders to the iron and steel industry is one that is becoming more indispensable as the demands for quality become more exacting. A large industry has been reared upon the exploitation and sale of such an alloy, and in another works it forms one of the principal products of the establishment. The success of Rossi after many years of endeavor is of an excellence so signal and so arresting that it is certain to reawaken the latent interest in

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other of the now rare elements; *e.g.*, boron, calcium, strontium, barium, magnesium, zirconium, and others.

In any presentation of this subject, one is confronted by a number of difficulties, so that no attempt has been made to set forth an exhaustive treatise. The subject naturally falls under these heads: mineralogy and geology of titanium; chemistry of titanium; titanium in iron and steel and in non-ferrous metallurgy; and the uses of titanium and its compounds. These items, while not treated *seriatim*, are discussed in the paragraphs herein. The work, of necessity, has called for somewhat of a compilation of the writings of various authors, so I hope to be excused from what might appear to be an indiscriminate plagiarism. This can scarcely be avoided under the circumstances.

Acknowledgments.—Mr. A. Thompson, general manager of The Titanium Alloy Manufacturing Company, Niagara Falls, N. Y., kindly provided me with a set of titanium-treated Bessemer and open-hearth steels, and corresponding non-treated steels for comparison. Mr. Geo. F. Comstock, metallographist for the same company, has accorded me permission to reproduce some of his photomicrographs. Dr. Thos. L. Watson, director of the Virginia Geological Survey, has allowed me permission to show some of his photographs, as have Mr. Van H. Manning, director of the United States Bureau of Mines, and Dr. Joseph T. Singewald, Jr., of Johns Hopkins University. I have also shown some illustrations with the permission of the Goldschmidt Thermit Company, New York City, and Mr. George B. Waterhouse, Lackawanna Steel Company, Buffalo, N. Y. These courtesies are fully acknowledged in the text.

2. THE CHEMISTRY OF TITANIUM.

History of the Element and General Statement.—The element titanium was discovered by the Rev. William McGregor, in 1791,[1] while studying a magnetic black sand occurring at Menachan, Cornwall. In 1794,[1] Klaproth, while engaged in an investigation of rutile, discovered a new metal, which he named titanium. McGregor had given the name of menaccanite to the magnetic black sand, and to the newly discovered element the name mena-

[1] AUTHOR'S NOTE.—There is some difference of opinion as to the exact dates here; the first is given as 1789 and the second as 1795 in some writings.

chite. In an investigation of ilmenite some time later—1797, to be exact—Klaproth showed that titanium and menachite were one and the same element. At any rate, the name titanium has been universally adopted, and menachite is referred to only in historical considerations. Titanium is one of the 80-odd elements which either in combination or elemental make up the crust of the earth and the surrounding atmosphere. Relatively speaking, it is a common element, although long considered rare. Elemental titanium is unknown in nature, it being found most commonly in combination with oxygen, as titanium dioxide (TiO_2), in three minerals; viz., brookite, rutile, and anatase.

Physical and Chemical Properties.—Titanium [2] is a member of that group of elements to which also belong silicon, zirconium, cerium, and thorium. It bears a most marked resemblance to these elements, particularly in its tetravalency, although it has a lower valence in some cases; and it is, further, as is zirconium, either a weak base-forming or a weak acid-forming element. In its behavior towards reagents, titanium resembles tantalum to a certain extent. Titanium is a silvery-white metal—its color being not unlike that of highly polished steel; its fracture is steely. From a metallurgical standpoint, one of its most interesting properties is its workability; when cold it is brittle, but at a red heat it may be readily drawn and forged. The atomic weight is 48.1, and the specific gravity is given as 4.50. All attempts to draw it into wire have met with defeat on account of its non-ductility, either hot or cold, but, as stated, it is malleable at a low red heat and may be readily forged like iron. Hunter [3] determined the melting-point as between 1800° C. and 1850° C., and other determinations have been variable. Moissan [4] states that the element combines with oxygen with incandescence at a temperature of 610° C. On heating, it combines with the halogens and oxygen with incandescence to form halogen and oxygen salts, and with sulphur and carbon to form sulphides and carbides. Titanium combines with nitrogen with very great avidity,

[2] Roscoe and Schorlemmer, "Treatise on Chemistry," 1907, p. 787 *et seq.* Browning, P. E., "Introduction to the Rarer Elements," 1909, p. 99 *et seq.*

Hunter, M. A., "Metallic Titanium," *Jour. Am. Chem. Soc.*, vol. xxxii, 1910, p. 330 *et seq.*

[3] Hunter, M A., *loc. cit.*

[4] Moissan, H., "Traite de chemie minerale," tome ii, p. 494.

resulting in the formation of nitrides, resembling in this respect both boron and magnesium; the reaction commences at or about 800° C., and when the combustion of the metal occurs in air or in the presence of oxygen the oxide as well as the nitride is formed. Titanium is soluble in cold, dilute sulphuric acid, aqua regia, and hot concentrated hydrochloric acid; it is attacked rather more slowly by nitric acid, and more slowly still by dilute hydrofluoric and acetic acid.

Preparation of Metallic Titanium.—Whether pure metallic titanium had ever been prepared prior to the work of Hunter in 1900 is rather doubtful. The common methods which were employed, calling for a reduction of titanium dioxide (TiO_2) by heating with metallic sodium and magnesium, normally yielded contaminated products containing titanium monoxide in greater or less amount. The product yielded by the action of sodium on the halogen derivatives of titanium also contained small amounts of titanium monoxide, produced by the action of any moisture present; in the same method the nitride was often found in the product, due to the union of titanium and nitrogen. To exclude nitrogen in this method is exceedingly difficult and calls for delicate manipulation. The early investigators readily confounded the nitride with the element itself because of the confusing metallic appearance of the former; the compound formed by titanium with carbon and nitrogen (*i.e.*, titanium cyanonitride) was also thus confused.

Probably the nearest approach to the pure element, before the work of Hunter, was secured by Moissan. The French savant fused carbon with an excess of titanium dioxide in the electric furnace at exceedingly high temperature. From his procedure are secured three distinct products in as many different layers; viz., the top layer, consisting of titanium, with about 5 per cent. of carbon; the second layer, consisting of the nitride; and the third, or bottom, layer, consisting of titanium monoxide. If the top layer be again fused with an excess of titanium dioxide the carbon is reduced to 2 per cent. and the product is free from silicon and nitrogen.[5] Moissan employed, in his method, a magnesia or lime crucible for the fusion. The carbon in the product was no doubt in the form of the carbide, TiC (in the absence of high silicon this would be the normal occurrence), and

[5] Moissan, H., *Compt. Rend.*, 1895, vol. 120, p. 290.

in addition there was oxygen; the product was then almost anything but pure titanium. When prepared by the method just described, the product has a brilliant, white fracture and is extremely hard but is quite friable. Its specific gravity is higher than that of pure titanium, being 4.87. Moissan, in further work [6] on titanium, distilled the metal in the electric furnace; the distillate condensed in small crystals. The production of pure metallic titanium is difficult by reason of the high melting-point of the element, and this is augmented on account of its strong affinity for nitrogen, carbon, and oxygen. In addition to Moissan, other early workers who labored in the endeavor include Wollaston,[7] Rose,[8] Berzelius,[9] Wöhler,[10] and Deville,[11] as well as Nilson and Petersson.[12] The latter workers attempted the preparation of pure titanium by the reduction of titanium tetrachloride ($TiCl_4$) with sodium, by heating the materials to a red heat in an air-tight steel cylinder. The results were disappointing. Titanium, or rather the product secured by this process, is in the form of yellowish scales. The best product contained 94.73 per cent. titanium, and the chief impurity was oxygen. In the Goldschmidt and Rossi processes for the production of the pure metal, the reducing power of aluminum is taken advantage of. A modified Goldschmidt method [13] is employed, where a peroxide (usually barium or sodium peroxide) is introduced into the mixture to cause an accelerated rate of reaction and accordingly produce a higher temperature. Considerably more aluminum is needed, for the successful use of this method, than in the straight alumino-thermic method, to provide for combination with the oxygen of the peroxide.

Hunter [14] attempted to produce pure titanium by a number of processes, and among others repeated the work of Moissan and of Nilson and Petersson. Poor results were obtained by

[6] Moissan, H., *Compt. Rend.*, 1906, vol. 142, p. 673.
[7] *Phil. Trans.*, 1823, vol. 17.
[8] *Pogg. Ann.*, 1825, vol. 4, p. 3.
[9] *Pogg. Ann.*, 1837, vol. 14, p. 57.
[10] *Compt. Rend.*, 1849, vol. 29, p. 505.
[11] *Compt. Rend.*, 1857, vol. 45, p. 480.
[12] *Zeit. physikal. Chem.*, 1887, vol. 1, p. 25.
[13] Kuhne, K. A., *Electrochem. and Met. Ind.*, 1909, vol. vii, p. 127.
[14] Hunter, M. A., "Metallic Titanium," *Jour. Am. Chem. Soc.*, 1910, vol. xxxii, p. 330 *et seq.*

all the methods employed until he used the method of Nilson and Petersson and employed most rigorous care. He then succeeded in producing virtually pure titanium. Hunter used titanium tetrachloride formed by the chlorination of titanium carbide; the chloride was fluxed in a current of nitrogen in order to completely remove all traces of chlorine, and then distilled repeatedly with the rejection of the end fractions. That fraction boiling near 136° to 137° was then shaken repeatedly with sodium amalgam and mercury and redistilled, producing a water-like substance boiling at constant temperature. Five hundred grammes of the titanium chloride and 245 grammes of sodium (the amount required theoretically for the complete reduction of the titanium) were mixed and placed in a steel bomb. The bomb and the enclosed mixture were brought to a low red heat—the reaction taking place. On cooling, the contents were leached with water; the residue consisted of pure titanium, partly as a fine, gray powder and partly as small, rounded beads. The reaction taking place in the bomb is rapid, and the heat generated is enough to melt some of the metal—hence the appearance of part of the product as small beads. That the product is pure titanium is shown by two analyses of the small beads; viz., 99.90 per cent. and 100.20 per cent. titanium. The method just described is standard for the production of pure titanium.

Compounds of Titanium.—According to Browning,[15] the following are typical compounds of titanium; viz., oxides, TiO, Ti_3O_4, Ti_2O_3, Ti_7O_{12}, TiO_2, Ti_2O_5, TiO_3; hydroxides, $Ti(OH)_4$, $Ti(OH)_6$; chlorides, $TiCl_3$, $TiCl_4$; bromide, $TiBr_4$; iodide, TiI_4; fluoride, TiF_4; titanofluorides, R_2TiF_6, etc.; sulphides, Ti_2S_5, TiS_2; sulphates, $Ti_2(SO_4)_3$, $Ti(SO_4)_2$; nitrides, Ti_3N_4, Ti_5N_6, TiN_2; carbide, TiC; silicide, TiSi; titanates, $RTiO_3$, R_2TiO_3; acids (see hydroxides), H_2TiO_3.

Oxides.—Titanium combines with oxygen to form a number of oxides, the most important being titanium dioxide (TiO_2), titanium sesquioxide (Ti_2O_3), and titanium peroxide (TiO_3). In addition to these, the monoxide (TiO) has been prepared and others have been described. The existence of some of these latter is doubtful. Titanium dioxide is trimorphous, occurring as three different minerals; viz., rutile, brookite, and anatase, as

[15] Browning, P. E., "Introduction to the Rarer Elements," 2nd ed., 1909, p. 99.

already mentioned. Titanium dioxide fuses at the temperature of the oxyhydrogen flame, forming a thin liquid which solidifies to a confused crystalline mass. In point of stability no other known compound surpasses TiO_2. Its heat of formation has been determined by W. G. Mixter [16] to be about 218,000.

The compound of titanium most deserving of the attention of the metallurgist, because it is the most useful, is the carbide (TiC). In combination with iron, it is found in the commercial alloy known as "ferro-carbon titanium." When titanium carbide is heated to redness in oxygen or in the air, it reacts with vigor with oxygen in a manner not unlike pure metallic titanium. The interesting compound titanium cyanonitride may be mentioned in this connection. When iron ores containing titanium are reduced in the blast furnace, small, brilliant, copper-colored cubes are found in cavities of the slag and pig iron, and replacing mortar in the fire-brick lining. A mass containing 80 pounds was found in a blast furnace in the Harz. The crystals are hard enough to scratch glass, and are highly refractory. The compound was noted by Wollaston [17] in 1822; he, at the time, thought it to be pure titanium, like many of the other early investigators. In 1849, Wöhler showed that it contained both nitrogen and cyanogen and ascribed to it the formula $Ti(CN)_2$, $3Ti_3N_2$. Its specific gravity is 5.28, and it is highly resistant to the attack of acids, being attacked only by a mixture of nitric and hydrofluoric acids.

3. THE GEOLOGY AND MINERALOGY OF TITANIUM.

Occurrence and Mineralogical Forms of Titanium.—Titanium is a constituent which is characteristic of certain pyrogenetic compounds. It is almost always found in igneous rocks and in the sediments derived therefrom. Clarke [18] states that out of 800 igneous rocks analyzed in the laboratory of the United States Geological Survey 784 contained titanium. The commonest occurrences of titanium are as ilmenite, rutile, titanite, and perofskite; and it is also often concentrated in beds of titanic iron ore. The element enters into the make-up of many minerals, but

[16] Mixter, W. G., *Am. Jour. Sci.*, January, 1912, vol. iii (ser 4), pp. 45–48.
[17] *Phil. Trans.*, 1823, vol. 17.
[18] Clarke, F. W., "The Data of Geochemistry," Bull. 616, U. S. Geological Survey, p. 21.

rather rarely in anything like considerable quantity in any given locality. It occurs in a variety of mineralogical forms, mainly as oxides, titanates, and silico-titanates; further, it enters into the composition of many silicates as well as certain tantalates and niobates. As the oxide—chiefly rutile—titanium occurs in some rock magmas comparatively poor in base formers but rich in silicon. Where there is sufficient calcium and titanium, calcium titanate (*i.e.*, perofskite) is formed. In magmas which are richest in iron and leanest in silicon, titanium combines with ferrous iron to form iron titanate; *i.e.*, ilmenite.[19] Titanium is quite frequently present in ferric oxide—hematite—in variable amount, and in iron ferrate; *i.e.*, magnetite. It is often found also in small amounts in biotite, augite, amphiboles, certain varieties of garnet, and in some other silicate minerals. Traces of it have been detected in trap and basalt. Its presence has been observed in mineral waters, in many clays, occasionally in certain coals, in meteorites, and in most fertile soils. It has been detected in the sun's atmosphere by means of the spectroscope. Small amounts of titanium have been found in certain varieties of woods, in the ashes of all plants, [20] and bone, [21] in cowpeas, and in cotton-seed meal. The titanium minerals given in Table I [22] have been recognized and described in the literature. Many of them are rare and of only academic interest.

TABLE I (after Watson and Taber).

*Titanium Minerals.**

Mineral	Composition	Contains TiO_2, per cent.
Oxides:		
Rutile†	TiO_2	100
Octahedrite (Anatase)	TiO_2	100
Brookite†	TiO_2	100
Titano-magnetite	Magnetite (Fe_3O_4) with variable TiO_2	Variable up to 25

[19] Iddings, J. P., "Igneous Rocks," 1909, vol. i, pp. 60, 64, 145.

[20] Wait, *Jour. Am. Chem. Soc.*, 1896, vol. 18, p. 402.

[21] Baskerville, Chas., *Jour. Am. Chem. Soc.*, 1899, vol. 21, p. 1099.

[22] Watson, T. L., and Taber, S., Bull. No. 111-A, Virginia Geological Survey, pp 10, 11.

*Compiled from Dana, E. S., "A System of Mineralogy"; Hintze, C., "Handbuch der Mineralogie," and other sources.

†Varieties omitted.

TABLE I (*Continued*).

Mineral	Composition	Contains TiO_2, per cent.
Titanates:		
Ilmenite †	$FeTiO_3$	52.7
Pyrophanite	$MnTiO_3$	53.1
Geikielite	$MgTiO_3$	67.7
Perovskite	$CaTiO_3$	58.9
Pseudobrookite	$Fe_4(TiO_4)_3$	42.9
Arizonite	$Fe_2O_3.3TiO_2$ or $Fe_2Ti_3O_9$	58.8
Knopite	$RO.TiO_2$. Closely related to perovskite, but contains cerium	64.1–58.7
Iserite	$FeTi_2O_5$	69.5
Titano-silicates:		
Titanite †	$CaTiSiO_5$	40.8
Schorlomite	$3CaO.(Fe,Ti)_2O_3.3(Si,Ti)O_2$	12.5–22.1
Keilhauite	$15\ CaTiSiO_5.(Al,Fe,Y)_2(Si,Ti)O_5$	26.7–36.6
Guarinite	$CaTiSiO_5$	40.8
Tscheffkinite	Related to keilhauite but uncertain	16.1–21.2
Astrophyllite	$(Na,K)_4(Fe,Mn)_4Ti(SiO_4)_4$	7.1–13.6
Aenigmatite	$2Na_2O.9FeO.Al_2O_3.12(Si,Ti)O_2$	5.6
Cossyrite	Similar to aenigmatite	Undetermined
Yttrotitanite	See keilhauite	See keilhauite
Lamprophyllite	Related to astrophyllite	Undetermined
Neptunite	$R_2RTiSi_4O_{12}$	18.1
Johnstrupite	A complex silicate of the cerium metals, Ca and Na chiefly, with Ti and F	7.6
Mosandrite	Very near Johnstrupite	5.3–9.9
Rinkite	Near Johnstrupite and mosandrite	13.4
Ivaarite	Similar to schorlomite	18.98
Carlosite	Same as neptunite	18.1
Benitoite	$BaTiSi_3O_9$	19.3
Lorenzonite	$Na_2(TiO_3)Si_2O_7$	35.2
Yttrocrasite	A hydrous titanate of the yttrium earths and thorium	49.7
Delorenzite	$2FeO.UO_3.2Y_2O_3.24TiO_2$ (?)	68.9
Davidite	TiO_2 with Fe, U, V, Cr, and rare earths	50.0+
Narsarsukite	Acid titano-silicate of ferric iron and sodium	14.0
Niobates and Tantalates:		
Pyrochlore	$RNb_2O_6.R(Ti,Th)O_3.NaF$	5.4–13.6
Aeschynite	$R_3Nb_4O_{12}.R_3(Ti,Th)_4O_{12}$	21.2
Polymignite	$R(Nb,Ta)O_3.5R(Ti,Zr)O_3$	18.9
Euxenite	$R(NbO_3)_3.R_3(TiO_3)_3.\frac{1}{2}H_2O$	20.0–23.5

†Varieties omitted.

TABLE I (*Continued*).

Mineral	Composition	Contains TiO_2, per cent.
Polycrase	$R(NbO_3)_3$. $2R_2(TiO_3)3H_2O$	25.2–29.3
Blomstrandite	A niobate, tantalate and titanate of uranium	10.7
Dysanalyte	$6RTiO_3RNb_2O_6$	40.6–59.3
Strüverite	$FeO(Ta,Cb)_2O_5$. $6TiO_2$ (?)	44.0
Epistolite	$Nb_2O_5.SiO_2.TiO_2.Na_2O.$ H_2O (?)	7.2
Blomstrandine-Priorite	Niobates and titanates of Y, Er, Ce. and U	21.9–32.9
Marignacite	Same as pyrochlore	2.9
Ilmenorutile	$FeO,Nb_2O_5.5TiO_2$	53.0–73.8
Silicates:		
Amphibole	$CaR_3(SiO_3)4$. Variable amounts of TiO_2	As much as 8.5
Pyroxene	$CaR(SiO_3)_2$. Variable amounts of TiO_2	As much as 4.6
Biotite	$(H,K)_2(Mg,Fe)_4(Al,Fe)_2(SiO_4)_4$. Variable amounts of TiO_2	Variable up to 4.7
Lepidomelane	Iron mica, with variable amounts of TiO_2	Variable up to 4.7
Rosenbuschite	$6CaSiO_3.2Na_2ZrO_3F_2.(TiSiO_3.TiO_2)$	6.9–7.6
Titanolivine	Olivine $(Mg,Fe)_2SiO_4$ with variable TiO_2	3.5–6.1
Andradite	$Ca_3Fe_2(SiO_4)_3$; also $Ca_3Fe_2(Si, Ti)O_4)_2$ with variable TiO_2	Variable up to 10.8
Leucosphenite	$Na_2Ba_2(TiO_3)$ $(Si_2O_5)_2$	13.2
Rhönite	$(Ca,Na_2K_2)_2Mg_4Fe_2Fe_3Al_4(Si,Ti)_6O_{20}$	9.5
Miscellaneous:		
Hydrotitanite	Altered form of dysanalyte	82.8
Warwickite	Perhaps $6MgO.FeO.2TiO_3.3B_2O_3$	23.5
Zirkelite	$(Ca,Fe)O.2(Zr,Ti,Th)O_2$	14.95
Derbylite	$6FeO.5TiO_2Sb_2O_5$	34.6
Lewisite	$5CaO.2TiO_2.3Sb_2O_5$	11.7
Mauzeliite	$4(Ca,Pb)O.TiO_2.2Sb_2O_5$	7.9
Hainite	Composition doubtful, probably allied to mosandrite	Undetermined
Senaite	$(Fe,Pb)O.2(Ti,Mn)O_2$. Uncertain	57.2

Titanium Ores.—A resurvey of the titanium ores is somewhat of an idle ceremony; however, the source of titanium commercially is confined exclusively to the titanium ores, there being but three at the present writing, viz., rutile, ilmenite, and titaniferous magnetite. That the latter has immense potentialities is the firm conviction of a number of metallurgists, although most

of the investigations leading towards a method for their utilization have ended negatively. Many of the titaniferous magnetites are too low in titanium content to be now regarded as ores, although they might become so. As already alluded to in the foregoing, titanium is quite extensively distributed in sundry mineralogical forms, but the only ones of commercial value are those just mentioned. A great many other forms of titanium are either too rare, or too complex in composition, or are not found in sufficient quantity to be of value. Their interest chiefly is an academic one. To consider the ores of titanium specifically, it is found that of the many oxides of titanium occurring in nature but one of them is important as an ore; *i.e.*, rutile.

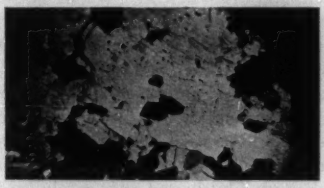
Rutile.—This mineral occurs as a pyrogenetic mineral in eruptive rocks, but it is more commonly found in gneiss, mica schist, and the phyllites. Rutile is also found as a secondary mineral, derived from ilmenite and titanite. It crystallizes in the tetragonal system commonly in prismatic crystals vertically striated or furrowed, and often acicular; it may be found also compact, massive to coarse and fine granular. Several kinds show marked and frequent twins. Composition, TiO_2 when pure. The mineral is brittle, with a hardness of 6 to 6.5, Mohr, and specific gravity 4.18 to 4.25 and up to 5.2 in a black variety with 10 per cent. FeO. The cleavage is distinct and the fracture subconchoidal to uneven; lustre is adamantine to metallic. Rutile is usually reddish-brown in color, passing into red; and it may be black, violet, yellowish, bluish, and very rarely grass green. The streak is pale brown. Rutile contains 40 per cent. oxygen and 60 per cent. titanium. Vanadium in disappearingly small amount and iron up to 10 per cent. are quite often present; at times chromium and tin are contained. The mineral is insoluble in acids and non-fusible under the blowpipe. It has a molecular volume of 19.1 and a molecular weight of 80.1. As referred to above, rutile is found in igneous, metamorphic, and sedimentary rocks. In the first named it may be either as an alteration product or a pyrogenetic constituent. In the metamorphic rocks, such as amphibolites, phyllites, gneisses, and mica schists, it is a common constituent, and it occurs more rarely in dolomite and granular limestone. Emmons[23] states that rutile is formed in igneous rocks, pegmatite dikes, contact metamorphic deposits, deposits of

[23] Emmons, W. H., "A Genetic Classification of Minerals," *Econ. Geol.*, 1908, vol. iii, p. 621.

the deep vein zone, and as a product of dynamo-regional metamorphism. Rutile is an exceedingly stable mineral, but at times alters to leucoxene. Two other modifications of titanic oxide are brookite and anatase. Brookite alters into rutile, and rutile into ilmenite, anatase, and sphene, so that the titanium minerals are thus closely linked. The known distribution of rutile in commercial deposits is limited indeed. The more important ones are confined to two localities in Virginia, U. S. A., and one each in Canada, Europe, and Australia.

Rutile in Norway.—The most important locality at which rutile occurs commercially in Norway is near Kragerö, on the southeastern coast. As mentioned by W. C. Brögger and T. L. Watson,[24] the rutile here occurs in a large aplitic dike, referred to as rutile aplite. A thin section of the rock examined under the microscope shows feldspar, much rutile, quartz, and ilmenite in subordinate amount, as illustrated in Fig. 1.

FIG. 1.



Kragerite, a rutile-bearing aplite, from Kragerö, Norway. Black grains and crystals are rutile, light areas chiefly sodic feldspar (albite-oligoclase). Nicols crossed. ×30 diameters and reduced one-half. (After Watson and Taber.)

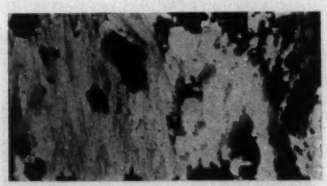
Rutile in Australia.—The only commercial occurrence of rutile in this country is near Mount Crawford, in South Australia, but other non-commercial occurrences are known. Little has been published on their geology. Hand specimens of ore from the leases of one F. J. Spence show chiefly a granular mixture of dark-red rutile and light silicate minerals, the principal ones of which include sillimanite, sericite, quartz, and, infrequently, feldspar. Broken and mashed sillimanite fibres, fractured rutile and quartz, etc., are some of the pressure effects of metamorphism revealed in the thin section, illustrated in Fig. 2.

Rutile in Virginia.—In "The Geology of the Titanium and

[24] Watson, T. L., "A Rutile-bearing Rock from Kragerö, Norway," *Am. Jour. Sci.*, 1912, vol. xxxiv, pp. 509–514.

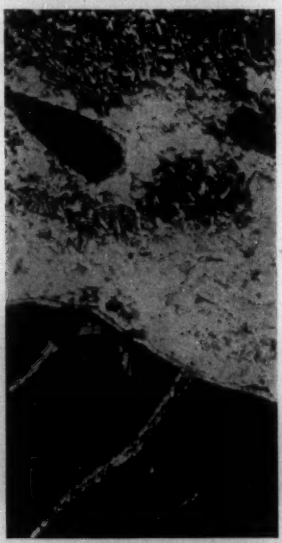
Apatite Deposits of Virginia," by Thomas L. Watson and Stephen Taber, the occurrences of commercial rutile ores are described at length and in a masterly manner; any mention in this place

FIG. 2.



Rutile-bearing pegmatite (?) from South Australia. Black areas rutile, light areas in right half of figure feldspar and quartz, medium-gray and light fibrous areas in left half sillimanite. Nicols crossed. × 30 diameters and reduced one-half. (After Watson and Taber.)

FIG. 3.



Rutile-bearing syenite, American Rutile Company's quarries at Roseland, showing rutile (the two dark grains in upper part of figure and the mass in lower half) rimmed by the alteration product leucoxene. Note the same alteration product filling fracture crossing rutile mass in lower half of figure. Nicols crossed. × 30 diameters (After Watson and Taber.)

seems superfluous. However, sufficient to say that the Virginia deposits are of particular interest because of their scientific and commercial importance. They are the only known workable rutile deposits in this country. The rutile area of Virginia lies

FIG. 4.

Blue quartz in syenite filled with inclusions of rutile needles. General Electric Company's mine. Nicols crossed. X 375 diameters and reduced one-half. (After Watson and Taber.)

in Amherst and Nelson counties, about half way between Charlotteville and Lynchburg. Practically the entire production of rutile in the state has been turned out by the American Rutile Company at Roseland; the mill of the company has seen more

FIG. 5.

Mill and surface plant of the American Rutile Company, Roseland. (After Watson and Taber

or less intermittent operation, due to market conditions. Without going into detail, the rutile-bearing rock of the American Rutile Company's property is a syenite. A micro-thin section

(see Fig. 3) shows typically the secondary alteration production leucoxene, as well as the dark rutile. Rutile as microscopic hairlike inclusions is abundantly developed in the quartz in some places; this is typically shown in Fig. 4. Most of the rutile mining has been carried on by the American Rutile Company, at its Roseland mill, shown in Fig. 5.

There are given in tabular form in Table II analyses of typical rutile concentrates produced by the company. The concentrates naturally fall into two divisions by reason of their treatment; viz., those treated by magnetic machines, and those not so treated. The difference in treatment reveals itself in the analyses; those concentrates not treated magnetically showing low titania and high iron, and *vice versa*.

TABLE II.[25]

Commercial Analyses (Partial) of Rutile Concentrates From the American Rutile Company's Property.

No.	TiO_2	Fe.	SiO_2	Analyst
1....	99.22	0.44	....	Waller and Renaud, New York City.
2....	98.60	0.40	1.20	General Electric Company's laboratory, Schenectady, N. Y.
3....	98.42	0.48	....	Waller and Renaud, New York City.
4....	97.54	1.17	....	Ricketts and Banks, New York City.
5....	96.50	0.42	0.77	Waller and Renaud, New York City.
6....	95.18	1.28	....	Ledoux and Company, New York City.
7....	94.65	2.15	....	Simonds and Wainright, New York City.
8....	94.47	2.76	0.51	Waller and Renaud, New York City.
9....	94.34	4.05	....	Waller and Renaud, New York City.
10....	94.12	1.58	....	Waller and Renaud, New York City.
11....	93.22	2.26	....	Ledoux and Company, New York City.
12....	93.14	4.40	....	Waller and Renaud, New York City.
13....	92.94	5.46	....	Waller and Renaud, New York City.
14....	91.24	8.02	....	Waller and Renaud, New York City.
15....	90.58	5.82	....	Waller and Renaud, New York City.
16....	90.10	5.01	1.95	Simonds and Wainright, New York City.
17....	89.91	3.46	....	Ledoux and Company, New York City.
18....	89.85	8.85	....	Waller and Renaud, New York City.
19....	89.30	7.33	0.70	Waller and Renaud, New York City.
20....	89.08	2.99	....	Ledoux and Company, New York City.
21....	88.73	7.06	....	Waller and Renaud, New York City.
22....	88.08	9.45	....	Waller and Renaud, New York City.
23....	87.16	7.33	0.44	Waller and Renaud, New York City.
24....	86.18	8.24	....	Ledoux and Company, New York City.
25....	85.90	9.60	....	Ledoux and Company, New York City.
26....	85.60	10.92	....	Waller and Renaud, New York City.

[25] Watson, T. L., and Taber, S., "Geology of the Titanium and Apatite Deposits of Virginia," Bull. III-A, Virginia Geological Survey, p. 173.

Ilmenite.—This is the only one of the many titanites which is important as an ore of titanium. It is a heavy, black mineral crystallizing in the hexagonal system, being rhombohedral. The chemical composition is very variable; if normal, the formula is $FeTiO_3$, corresponding to 47.3 per cent. FeO and 52.7 per cent. TiO_2. There is an isomorphous series, $(Fe,Ti)_2O_3$, with varying amounts of iron and titanium grading down to hematite (Fe_2O_3). Rarely are good megascopic crystals of ilmenite observed; the mineral normally is seen as embedded grains and in masses, although often as irregular plates, and as sand; *e.g.*, in the black sand at Menachan, Cornwall. The cleavage is obscure and the fracture is conchoidal. Ilmenite is brittle, with a hardness of 5 to 6 and a specific gravity of 4.5 to 5.0. The color is iron black, but it occasionally shows a brownish or reddish tinge. The streak is black to brownish-red. Usually it is slightly magnetic, but not always. The molecular weight is 152, and the molecular volume 30.4. In nature, ilmenite is widely diffused, occurring as an essential constituent in diorite, gabbro, diabase, and basalt, and related rocks. It is isomorphous with, or occurring with, hematite in granite and syenites.[26] In many metamorphic rocks, as amphibolites, mica schist, and gneiss, particularly, is ilmenite found. According to Lindgren[27] and Emmons,[28] ilmenite is formed in igneous rocks, in pegmatites, in contact metamorphic deposits, in deep veins, and under regional-metamorphic actions. The mineral has been little investigated on the synthetic side, but its constitution has been much discussed.

Titaniferous Magnetites.—The importance of the titanium-bearing magnetites is such that a separate division of this writing immediately following is devoted to their consideration.

4. TITANIFEROUS MAGNETITES.

In General.—American and other ironmasters are confronted with the important problem of the reduction on a large scale of titaniferous magnetites containing titanium in large amount. Large bodies of easily mined titanium-bearing magnetites have

[26] Clarke, F. W., "The Data of Geochemistry," U. S. Geological Survey, Bull. 616, p. 348.

[27] Lindgren, W., "The Relation of Ore Deposits to Physical Conditions," *Econ. Geol.*, 1907, vol. ii, p. 125.

[28] Emmons, W. H., "A Genetic Classification of Minerals," *Econ. Geol.*, 1908, vol. iii, p. 621 *et seq.*

been discovered from time to time, and a voluminous mass of contemporaneous literature is at hand dealing with their geological occurrence and probable economic value. The approach, in the not far distant future, of the possible exhaustion of the deposits of non-titaniferous iron ores, and the use in blast-furnace plants now of lower tenor iron ores than formerly, point the way to the necessity of some time turning to the titanium-bearing material for smelting. The general feeling among works managers is that iron ores containing in excess of one per cent. of titanium are difficult to smelt in the furnace, in spite of the demonstrations of Rossi and other workers to the contrary. It appears, according to the experiments of Rossi, that titanium may be eliminated by producing comparatively fluid titano-silicate slags. Still, there is little hesitancy on the part of furnace men in stating that they cannot change their practice in order to conform to such requirements. Dr. J. T. Singewald, Jr., in an able dissertation,[29] points out the feasibility of using the concentrates from a magnetic process for treating titaniferous ores in a blast-furnace mixture with high-grade hematite. The reduction of titanium-rich ores by electric smelting is a problem of importance and has the serious consideration of those interested in their being used. The milling problem is one that is more annoying than is generally supposed, by reason of the manner of occurrence of the titanium in the ores. Off-hand it would seem as though magnetic separation would effectively separate the ilmenite and the magnetite. Micrographic examination has shown that the ilmenite in most of the large deposits occurs in such fine intergrowths that a clean separation of the two minerals cannot be effected by any method employing variation in their physical properties. In a word, the problem is metallurgical and involves a direct smelting of the ores.

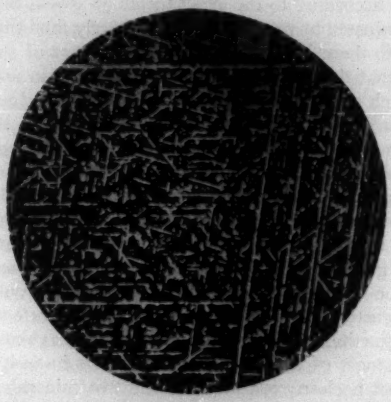
Mineralogy and Geology of Titaniferous Magnetites.—The manner in which titanium occurs in titaniferous magnetites is a question of importance; it is one which has been discussed at great length, and one on which divergent opinions have been expressed with great freedom. Previous to the work of Singewald [30] there had been but little systematic scientific attempt made

[29] Singewald, J. T., Jr., "The Titaniferous Iron Ores of the United States," Bull. 64, Bureau of Mines, 1913.

[30] Singewald, J. T., Jr., "The Microstructure of Titaniferous Magnetites," *Econ. Geol.*, vol. viii, No. 3, April–May, 1913, p. 207 *et seq.*

to solve the problem. Some writers claimed that the ores were mechanical aggregations of magnetite and ilmenite; others stated that the titanium was a part of the magnetite molecule, replacing a part of the iron. Regardless of which view is correct at this juncture, let it be said that the question is one of keen practical import, and not one merely of academic interest. If, as has been stated, titanium is part of the magnetite molecule, no process of mechanical separation can successfully work. If, on the other hand, as has been claimed by some, the ores are aggregates of magnetite and ilmenite, such separation is possible; since

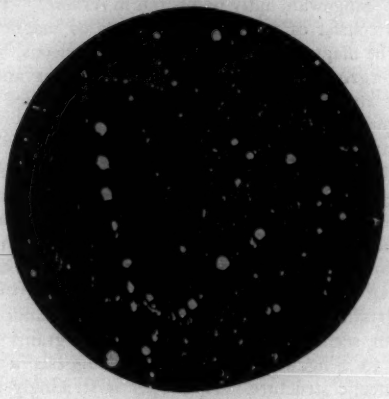
FIG. 6.



Lines show sections of minute ilmenite lamellæ, oriented parallel to the octahedral face of the magnetite. ×60 diameters. (After Singewald.)

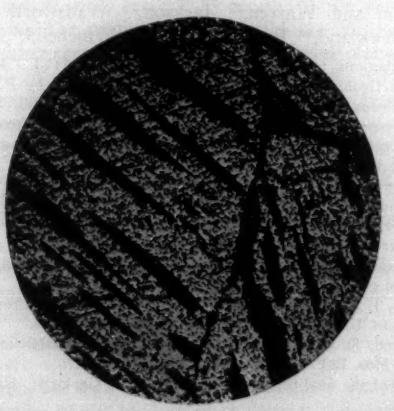
magnetite is strongly magnetic, and ilmenite only feebly so or not magnetic at all, crushing followed by treatment on a magnetic separator should separate the two. A great many experiments on different ores have been made employing magnetic processes, and varying degrees of success have been obtained. At any rate, the tests appear to indicate that the ores consisted of aggregates of magnetite and ilmenite to a varying extent; they demonstrated also that the magnetite grains contained titanium. Singewald picked out grains of magnetite so separated, showing no ilmenite intergrowths on etching, and found by analysis that such grains showed an appreciable titanium content, and, in one

FIG. 7.



Dot intergrowths of ilmenite showing rectilinear orientation parallel to the octahedral magnetite cleavages. × 60 diameters. (After Singewald.

FIG. 8.



Lenticular bands of magnetite in ilmenite. × 60 diameters. (After Singewald.

case, 6.6 per cent. Ti. This points to the existence of a titanomagnetite. Singewald aptly points out in *résumé:* "Titaniferous magnetites consist of granular aggregates of magnetite and ilmenite. The magnetite is usually not homogeneous, but contains minute intergrowths of ilmenite in both regular and irregular orientation, and may contain a considerable percentage of titanium in the magnetite molecule itself."

On examination of black magnetite ores under the microscope, it may be readily observed that, in some cases, they are non-homogeneous and contain minute ilmenite intergrowths. The most commonly noted forms of such intergrowths are as lines and dots showing in the section. Such line intergrowths are seen in Fig. 6; dot intergrowths showing in approximately circular outline are seen in Fig. 7. Another form of intergrowth is that noted in certain Canadian ores, consisting of a banded lenticular arrangement, seemingly bands of magnetite in grains of ilmenite. According to Singewald, the structure suggests a magnetite-ilmenite eutectic structure. This latter is strikingly revealed in Fig. 8.

Occurrence of Titaniferous Magnetites.—This subject has been treated at length in the current technology by such writers as Johnson and Warren,[31] Jackson,[32] Wadsworth,[33] Dana,[34] Kemp,[35] Newland,[36] Bayley,[37] Nitze,[38] Winchell,[39] *et al.* The

[31] Contributions to the Geology of Rhode Island: I. "Notes on the History and Geology of Iron Mine Hill, Cumberland," by B. L. Johnson. II. "The Petrography and Mineralogy of Iron Mine Hill, Cumberland," by C. H. Warren; *Am. Jour. Sci.*, 4th ser., vol. 25, January, 1908, pp. 1–38.

[32] Jackson, C. T., "Report on the Geological and Agricultural Survey of the State of Rhode Island," 1840, p. 52.

[33] Wadsworth, M. E., "A Microscopic Study of the Iron Ore or Peridotite of Iron Mine Hill, Cumberland, R. I.," Mus. Comp. Zool., Harvard College Bull. 7, 1881, pp. 183–187, and "Lithological Studies," Mem. Mus. Comp. Zool., Harvard College, vol. ii, 1884, p. 80.

[34] Dana, J. D., "Iron Ore of Iron Mine Hill, Cumberland, R. I.," *Am. Jour. Sci.*, 3d ser., vol. xxii, 1881, p. 152.

[35] Kemp., J. F., "The Titaniferous Iron Ores of the Adirondacks," 19th Annual Report U. S. Geol. Survey, pt. 3, 1899, pp. 377–422.

[36] Newland, D. H., "Geology of the Adirondack Magnetic Iron Ores," N. Y. State Mus. Bull. 119, pt. 3, 1908, pp. 152–156.

[37] Vol. 7 of the final report series of the State Geologist, 38, New Jersey, 1910.

[38] Nitze, N. B. C., "A Preliminary Report on the Iron Ores of North Carolina," North Carolina Geol. Survey, Bull. 1, 1893.

[39] Winchell, H. V., "Seventeenth Annual Report of the Geological and Natural History Survey of Minnesota," 1888, pp. 80–81.

most recent summation is the able treatise of Singewald, referred to earlier in the text. Suffice it to say that the deposits are widely diffused, but occur in workable deposits at but two places in this country; viz., those at Lake Sanford, New York, and at Iron Mountain, Wyoming. The ores are nearly pure aggregates of magnetite and ilmenite, the roughly estimated tonnage of each running into millions (no accurate estimate has been made). The other titaniferous iron ores in the United States cannot be figured as sources of iron for many years, seemingly almost indefinite at the present writing. In view of the excellent work of Singewald, it appears a useless task to recall the data further in this short work.

Smelting of Titaniferous Magnetites: IN GENERAL.—In spite of prolix discussion at periodic intervals, the problem of smelting the titaniferous iron ores in the blast furnace as yet remains unsolved to the satisfaction of most metallurgists. Most realize that such ores have been smelted with marked success, but, in the main, the consumption of fuel for their reduction has been so high that the cost is well-nigh prohibitive. Ores containing over one per cent. of titanium are condemned as unsuitable for part of the blast-furnace burden mainly on account of the high fuel consumption, and, further, by reason of the formation of accretions and the production of scaffolding in the furnace, thereby choking the operation. A hasty survey shows that the consumption of such ores has greatly fallen off; nor is this to be wondered at, in view of the condition of the iron industry years ago and now.

Blast Furnace Smelting.—Disregarding here the pros and cons of the question, it appears that the titaniferous ores will in time find a place in the industry. Their great tonnage magnitude, as well as their ease of workability and freedom from sulphur and phosphorus, makes them highly desirable, particularly for Bessemer practice. At some furnace plants in Norway, Sweden, and England titaniferous iron ores were smelted as such in late years; at some plants titaniferous ore was admixed with non-titaniferous material to form the smelting charge. The deposits at Taberg, Sweden, were worked extensively for a number of years over a century ago, but their use has been practically abandoned with the introduction of the modern blast furnace. A furnace operated at Lake Sanford, New York, for sixteen years, beginning

in 1840, but this, too, has ceased activities. In 1873 the Canadian Titanic Iron Company built two blast furnaces near Bay St. Paul, but their life was of short duration.[40] In view of the high fuel consumption (*i.e.*, from 3000 to 6000 pounds, approximately, of charcoal per ton of iron), it is surprising that the work lasted as long as it did. Wherever the smelting of such ore has been tried the process has been a perfect technical success, but the high fuel consumption has made it impracticable commercially.

In this country the indefatigable investigator, A. J. Rossi, has made a thorough study of the problem and has set forth his results in several writings, his first review of the work being given out in 1890.[41] Rossi conducted extensive experiments with a view to making the smelting of titaniferous magnetites a commercial success. The best results were obtained by forming a tribasic slag of lime, magnesia, and alumina. The ores charged analyzed from about 18 to 20 per cent. TiO_2 and yielded good pig iron and readily fusible slags showing proper fluidity. Rossi's later experiments were particularly conclusive; still, no attempts have been made to follow out his lines of work on a large scale, and the ores are as yét in bad repute. Rossi's experiments[42] followed those first carried on by Forbes,[43] who was connected with the iron industry in southern Norway; *i.e.*, they were first for the purpose of finding easily fusible titanate slags.

In a summation of the results of his work Rossi very properly resumes:

1. "As anybody who may desire to make the experiment can verify, titanic acid can form definite compounds, perfectly fusible, if properly fluxed, containing as much as 35 to 40 to 50 per cent. of titanic acid, with alumina, lime, and magnesia as bases, and admissible as slags in blast-furnace work. Larger percentages still, such as 65 per cent., can enter into a compound and it remains fusible. The objections to the smelting of titaniferous ores on

[40] Harrington, B. J., "Notes on the Iron Ores of Canada, and Their Development," Geol. Survey Can., Report of 1873–74, pp. 249–251.

[41] Rossi, A. J., "Titanium in Blast Furnaces," *Jour. Am. Chem. Soc.*, vol. 12, 1890, pp. 90–117.

[42] Rossi, A. J., "Titaniferous Ores in the Blast Furnace," *Trans. A. I. M. E.*, 1893, vol. 21, pp. 832–864, and "The Smelting of Titaniferous Ores," *Iron Age*, i, 1896, pp. 354–356 and 464–469.

[43] Forbes, David, "On the Composition and Metallurgy of Some Norwegian Titaniferous Iron Ores," *Chem. News*, 1868, pp. 275–276.

account of the refractory character of the slags are not sustained by our practice or that of others, or by direct experiments on the properties of these compounds.

2. "In running a furnace under special conditions of temperature and pressure of blast no troubles have been experienced from the titanium deposits. We never observed any in our blast-furnace tests, and none are mentioned by Doctor Forbes in his practice in England and Norway.

3. "If these special conditions of lower heat, considered more favorable in smelting these ores, are held to imply against them a waste of fuel, it is a question whether this is not offset by the smaller amount of cinder to melt, the lesser quantity of fluxes necessary, and their indirect effect upon the productive capacity of the furnace, as well as the greater value of the pig metal obtained for specific and numerous applications. This is without taking into account the possibility of not submitting to it by a rapid driving and forcing the production, conditions which, to judge from our tests, could be easily realized with these ores."

Electric Furnace Smelting.—Direct smelting of iron ores by an electric furnace process is one whose full potentialities have as yet not been shown. In some quarters its success has been signal; still the knowledge *in toto* is so incomplete that final conclusions cannot be drawn. Experiments with the electrical reduction of titaniferous iron ores have been conducted by a number of workers at many places, but particularly of late by Eugene Haanel [44] in Canada. In 1907 a series of experiments was performed on an ore analyzing 17.82 per cent. TiO_2; the experiments were incomplete, so that the results were negative. Borchers [45] has discussed the investigations carried out at his Aachen laboratory. Tests have been carried on here for over twelve years with the object in view of reducing the iron and recovering the titanium. Leyner, in 1898–99, and Hupperty, in 1904, also worked along similar lines in Germany. Gustave Gin [46] treated

[44] Haanel, Eugene, "Report on the Experiments Made at Sault Ste. Marie, Ontario, under Government Auspices, in the Smelting of Canadian Iron Ores by the Electrothermic Process," Canadian Department of Mines, Mines Branch, 1907, pp. 85–86.

[45] Borchers, W., "Titaniferous Iron Ores: Smelting in the Electric Furnace," *Stahl und Eisen*, May 4, 1911, p. 1706.

[46] Gin, Gustave, "On the Electrical Reduction of Titaniferous Iron Ores," *Trans. Am. Electrochem. Soc.*, 1907, vol. xi, p. 291 *et seq.*

titaniferous iron ores from Norway in the electric furnace at the electrochemical plant at Jessains, Department of Aube, France, in 1901. His conclusions from the experiments are that the electrical reduction of titaniferous iron ores presents no special difficulties, and that the problem is a question of abundant and cheap water power.

Stansfield [47] has experimented considerably in this field, and some abstracted remarks from his writings are quoted:

"Although the possibility of the electric smelting of iron ores for pig iron cannot be definitely settled in a general way, there appears to be every probability that a process which yields steel instead of pig iron would be commercially possible in favorable localities. Steel could be made by smelting titaniferous iron ores in an electric furnace with a somewhat smaller amount of charcoal than would be needed for making pig iron, and the resulting metal could be transferred in the molten condition to an electrical steel refining furnace, where it could be made into finished steel. The cost of producing the crude steel from the ore would be a little more than that of producing pig iron, and the cost of refining the steel would be only a moderate addition to this, while the price obtainable for the finished product would be decidedly higher than could be obtained for pig iron.

"The writer has been associated with Mr. J. W. Evans in the development of a process in which the reduction of titaniferous ores to metal and the subsequent refining of the steel is carried out in a single furnace, and, while the details of the furnace construction and certain parts of the operation have not yet been fully worked out, the results have been so encouraging that it appears to be worth while to develop the process on a small working scale. With regard to the results so far obtained, it may be stated that titaniferous ores obtained from the Orton mine and containing about 7 per cent. of titanium have been smelted directly to steel, and that such steel, containing about one per cent. of carbon, has been found to possess unusually good qualities as a tool steel. The cost of smelting these ores and refining the steel can be determined fairly accurately from the figures published in regard to the electrical smelting of iron ores to pig iron and the electrical refining of molten steel. These figures

[47] Stansfield, Alfred, "Electric Smelting of Titaniferous Ores," *Can. Min. Jour.*, vol. 33, 1912, pp. 448-449.

are more dependable than data obtained from the small-scale experiments that have so far been made. The writer intends, however, in the near future to make further experiments on the reduction and refining of the steel in order to obtain direct information as to the cost of the process.

"There do not appear to be any definite limits as regards the percentage of titanium in ores suitable for this process, but the cost of smelting will, of course, increase with the proportion of titanium, both on account of the cost of fluxing it and on account of the smaller proportion of steel obtained. It seems probable, therefore, that the process will be applied to ores that do not contain more than 5 to 10 per cent. of titanium. Ores somewhat richer than this in titanium may be concentrated magnetically, so as to obtain a product which shall be at once richer in iron and poorer in titanium, and it may even be possible in some cases that the tailings from such a concentration process may be sufficiently rich in titanium to be smelted for ferro-titanium. Some ores containing too much titanium for steel making are not amenable to magnetic concentration, and these may be smelted with suitable admixture of non-titaniferous ores. It has been found that the electric furnace is more suitable than the blast furnace for the treatment of pulverized ores, and that magnetic concentrates can be smelted alone or with the addition of a moderate proportion of coarser ore.

"The use of titaniferous ores for making tool steel would appear to be very advantageous commercially, but cannot be expected to provide for a large consumption of these ores, and it is of interest to consider whether the process can be applied to the production of steel on a larger scale. One purpose for which this process would appear to be very suitable is for the production of steel castings. A good deal of difficulty is experienced in the production of steel castings which can be relied upon as being entirely sound, and ferro-titanium is used in some cases for producing soundness in steel castings. It seems very probable, therefore, that steel made directly from titaniferous ores will be particularly suitable for the production of steel castings, and this will afford a larger field for the electric smelting of these ores. With regard to the use of this process on a still larger scale—for the production of steel rails, for example—the writer would say that there appears to be no definite reason why rails should not be

made by this process, but would not care to speak definitely with regard to this until the process has been in operation on a working scale."

From the foregoing it may be observed that there has been no dearth of workers in this field of investigation; the reward for the solution of the problem promises to be rich.

5. USES OF TITANIUM AND ITS COMPOUNDS.

General Statement.—Certain compounds of titanium have long enjoyed use, though in limited amounts, mainly as refractory coloring agents in ceramics. The pure element has not been used to any extent, because of its high melting-point, but titanium alloys have of late found rather far-reaching employment in the metallurgy of the non-ferrous metals, as well as in iron and steel. Recent developments in the use of the electric furnace, with its concomitant high temperatures, have encouraged the exploitation of processes for the reduction of titanium from its mineral ores, as well as the manufacture of titanium alloys on a large scale.

A better classification than that of Watson and Taber [48] concerning the useful products in which titanium is an important constituent can scarcely be made, viz.:

A. Metallic alloys, such as ferro-titanium and cupro-titanium.
B. Incandescent media for lighting purposes, including gas mantles, arc-lamp electrodes, and filaments for incandescent electric lamps.
C. Mordants and dyes for leather and textiles.
D. Refractory coloring material for use in ceramics and the manufacture of artificial teeth, and
E. Miscellaneous.

These uses are considered in the following pages, with some attempt to allot space according to the relative importance of the same.

A. METALLIC ALLOYS OF TITANIUM.—Quite a large number of binary and a few ternary titanium alloys have been investigated, but the only alloys on the market for commercial consumption are ferro-carbon titanium, ferro-titanium, cupro-titan-

[48] Watson, T. L., and Taber, S., Bull. III-A, Virginia Geological Survey, 1913, p. 271.

ium, and mangano-titanium. The alloys of titanium with iron were the first to receive marked attention, and of late years their use has increased largely, particularly by reason of their being employed as purifiers in iron and steel metallurgy. The present presence of titanium as an active agent in the iron and steel industry is directly due to the labors of A. J. Rossi, the dean of American titanium investigators, who has devoted some thirty years in this field. In Germany, H. Goldschmidt brought out the first successful, practical process for the reduction of titanium from its ores by means of his now well-known alumino-thermic method.

Ferro-carbon Titanium.—This alloy, for use as a final deoxidizer in iron and steel metallurgy, is a product manufactured in this country by The Titanium Alloy Manufacturing Company, Niagara Falls, N. Y., and it is a development resulting from the introduction of the electric furnace for ferro-alloy production. Rossi's work leading up to the production of what is known as ferro-carbon titanium is summed up in the following: In 1892 he secured a patent pertaining to the reduction of titaniferous ores in the blast furnace; a little later he tried to produce a ferro-titanium alloy in the blast furnace and crucible, but was unable to secure an alloy showing high titanium content. Experimental work conducted with the electric furnace resulted in the production of a commercial ferro-titanium alloy for use in steel making. In the Rossi process the reduction takes place in a bath of aluminum, the aluminum as ingots or any other convenient form being melted in the electric furnace. Pig iron or scrap iron is next added to the charge, and then rutile is introduced into the bath; the temperature is raised to such a point necessary to start the reaction whereby the aluminum combines with the oxygen of the rutile. The rutile is thus reduced to metallic titanium and alloys with the iron. The resulting alloy is practically carbon-free.

In case ilmenite or titanic iron ore is used in place of rutile, a great deal more aluminum is required to reduce the ferric oxide, thus increasing the cost of manufacture, because the iron can be otherwise more economically reduced. Where the alloy is prepared by reducing oxide of iron and titanium with carbon in the electric furnace, the product will contain from 5 to 9 per cent. carbon, mainly in the form of graphite. Carbon is at present used

exclusively for the reduction by The Titanium Alloy Manufacturing Company, replacing the aluminum bath method, once used. The process is described at length in letters-patent, domestic and foreign. In Rossi's first patent [49] he specified the reduction of titaniferous ore and rutile by means of carbon in an electric-resistance furnace with the production of a ferro-alloy containing over 5 per cent. titanium and some carbon, the reduction occurring in a bath of molten iron. Titaniferous slag was to be treated in the manner just described in a similar patent.[50] Two years later he patented [51] a process calling for the reduction of titaniferous ores in a bath of molten reducing metal (*e.g.*, aluminum), as alluded to above, in the electric furnace. In 1901 he procured a patent [52] for the concentration of titanium in slag by the reduction of the silicon and iron of a titaniferous ore with carbon, the temperature of operation to be below the fusion point of titanium oxide (TiO_2).

At one plant ferro-carbon titanium is produced commercially in a Siemens electric furnace of 500-kilowatt size. Titaniferous ore, or slag, or rutile is introduced, mixed with the proper amount of carbon, onto the top of a molten bath of scrap iron or steel. The reduction takes place in the arc, and the product is tapped off. The titaniferous ore charged has this analysis: 34.36 per cent. TiO_2, 50.53 per cent. FeO, 4.14 per cent. SiO_2, and 2.20 per cent. Al_2O_3. Slag from the process, if high in titanium, is recharged. The product obtained from the reduction analyzes 10 to 15 per cent. Ti, 5 to 8 per cent. C, and 0.35 to 1.00 per cent. Si. If this alloy be refined, employing rutile as a decarbonizing agent, a product is secured analyzing 10 to 15 per cent. Ti, 0.35 to 1.00 per cent. Si, and less than 1 per cent. C. In order to cut down the titanium lost through volatilization, Rossi, in a late patent,[53] calls for the introduction of lime (CaO) onto the molten iron bath, following this with titanic oxide, lime, and carbon; this causes a reaction with the reduction of metallic titanium as follows:

$$TiO_2 + CaO + 5C = Ti + CaC_2 + 3CO$$

[49] U. S. Patent No. 609,466, August 23, 1898.
[50] U. S. Patent No. 609,467, August 23, 1898.
[51] U. S. Patent No. 648,439, May 1, 1900.
[52] U. S. Patent No. 668,266, Feb. 19, 1901.
[53] U. S. Patent No. 1,019,528, March 5, 1912.

The merit of ferro-carbon titanium and its use in iron and steel metallurgy will be dealt with a little later on.

Ferro-titanium.—By ferro-titanium is meant the binary alloy free from carbon as produced by the Goldschmidt Thermit Company. As already alluded to, a process by Rossi accomplishes the same thing. Both processes depend on the strong reducing power of metallic aluminum. In the Goldschmidt process the metallic oxides which are to be reduced are mixed with aluminum in the proper amounts, both oxides and the metal being in a finely powdered state. Ignition with a fuse brings some point of the mixture to the temperature at which aluminum and oxygen combine. Once started, the reaction proceeds to completion with the concomitant reduction of the oxides. The high cost of aluminum powder and the difficulty of securing a pure product are objections to the process. The reaction which takes place is according to the following:

$$3\,TiO_2 + 4\,Al = 3Ti + 2Al_2O_3$$

The reaction may also be started over a molten iron bath by the heat thereof. The product produced by the Goldschmidt thermit process contains from 5 to 6 per cent. Al alloyed with the titanium. This alloy has been used for a number of years in many European steel works as a final deoxidizer in casting practice. In a late patent [54] granted to Drs. Hans Goldschmidt and O. Weil, of Germany, assigned to the Goldschmidt Thermit Company, alloys higher in titanium are made. The purpose of these alloys is to provide a modicum for adding a higher percentage of titanium to iron and steel baths, thereby overcoming otherwise alleged objections to low titanium content alloys. These alloys contain 15 to 35 per cent. Ti, 1.5 to 3.5 per cent. Al, and the remainder Fe. The aluminum lowers the melting-point of the titanium by combining therewith to form a titanium-aluminum alloy, the alloying qualification being thereby increased, so it is stated. The titanium alloys when made by the alumino-thermic process are more expensive than those made in the electric furnace, and this is a cogent factor militating against their use.

The Ferro-carbon Titanium-Ferro-titanium Controversy.—Noting what has been said regarding the two alloys (*i.e.*, ferro-carbon titanium and ferro-titanium) being used in the metallurgy

[54] U. S. Patent No. 1,136,670, April 20, 1915.

of iron and steel and being manufactured by rival companies, it is no small wonder that the technical press has been deluged with arguments as to their merits. In view of the importance of the subject, the merits of the two alloys will be dealt with here. Before setting forth the respective claims of the supporters of each, it would seem that the whole question hinges on the matter of alleged carbides in the electric-furnace product, which have been claimed to prevent its ready solution in steel, so that it would not appear in that light to do the work of the carbon-free alloy. Yet there does not appear to be over 0.25 per cent. of combined carbon in the alloy containing as much as 9 per cent. carbon. The carbon is mostly in the form of graphite, and, on adding the alloy to the steel or iron, part of the carbon combines with the iron, forming Fe_3C, iron carbide, while the remainder is removed in the slag by rising to the surface of the bath.

At any rate, metallurgists have practically all agreed that the use of a small percentage of titanium in some form is of benefit to iron and steel, and to-day titanium alloys are used in practically every grade of steel, both low and high carbon, alloy and other special steels, and in iron. Doctor Goldschmidt [55] has made the statement that the carbon-free metals dissolve with greater ease than those same metals containing carbon, because the carbon is present in the form of carbides in the latter. Charles V. Slocum found that the carbon-free alloy was not at all adapted to the metallurgy of iron and steel in the rôle of a deoxidizer and purifier. The company he is connected with was forced to produce an alloy containing 5 to 8 per cent. carbon for this use. According to Mr. Slocum, the Rossi interests early put on the market a carbon-free ferro-titanium alloy which was illy received by users, and which was a complete failure. The cause of this is attributed to the presence of the aluminum, which not only made the steel brittle, but also tended to the formation of oxides, which were retained as inclusions in the metal.

In this country, what is referred to by the trade as "titanium alloy" is usually the ferro-carbon titanium alloy of The Titanium Alloy Manufacturing Company. The alloy contains from 5 to 8 per cent. carbon, mostly in the form of graphite, the com-

[55] Goldschmidt, Hans, "The Melting-point and its Relation to Alloying Capacity," *Met. and Chem. Eng.*, 1911, vol. ix, p. 348.

bined carbon being present in small amount—in fact, disappearingly so. Analyses given in Table III show the relative amounts of combined and graphitic carbon made on four samples of the alloy.

TABLE III.

*Analyses of Ferro-carbon Titanium.**

Sample	Graphite	Combined carbon
1	9.601	0.147
2	9.179	0.120
3	7.012	0.130
4	6.234	0.118

*After The Titanium Alloy Manufacturing Company, Niagara Falls, N. Y.

The alloy of the above company is guaranteed to contain at least 15 per cent. titanium and has an average analysis as follows:

Ferro-carbon Titanium.

Silicon	1.41 per cent.
Titanium	15.79 per cent.
Carbon	7.46 per cent.
Manganese	0.11 per cent.
Aluminum	0.80 per cent.
Phosphorus	0.05 per cent.
Sulphur	0.08 per cent.
Iron (by difference)	74.30 per cent.
	100.00 per cent.

It is held by some that titanium acts much as does silicon in the manner of throwing carbon out of combined form into the graphitic state, and there is no ground for the belief that the carbon present in the triple alloy is mainly there as combined carbon. George B. Waterhouse,[56] who has used considerable quantities of this alloy in Lackawanna practice, draws attention to an interesting incident: Iron for the production of malleable castings was treated in the ladle with a titanium alloy, and the poured metal showed on fracture a white border from 1 to 1.25 cm. thick and a gray centre, indicating the presence of graphite; the same metal not so treated showed a fracture perfectly white, with very little gray in the centre. The density of deoxidizers, used as the titanium alloys are used, has an important bearing on their proper incorporation in the molten bath. The density of the 10 to 15 per cent. ferro-carbon titanium is from 6.20 to 6.40, being approximately the same as the Goldschmidt product.

[56] The Lackawanna Steel Company, Buffalo, N. Y.

In support of the other alloy, Doctor Goldschmidt claims that the ferro-titanium containing aluminum, as made by his company, is a far better and more efficient agent than the lower percentage titanium alloy containing carbon. His contention is that the aluminum is requisite and essential. In replying to Mr. Slocum's remarks in a discussion in the proceedings [57] of the American Electrochemical Society, he states that the ferro-titanium alloy which contains no aluminum, or only very little, alloys with the steel with great difficulty. It appears that, in 1897, the Goldschmidt interests placed a 35 to 40 per cent. titanium alloy on the market, which, it is claimed, did not find a ready sale, nor was a similar low-percentage alloy a success commercially. The alloy containing one part Al to three to four parts Ti was finally evolved and is now one of the principal products of the Goldschmidt Thermit Company. Doctor Goldschmidt holds that the aluminum is a necessary constituent, and that it has a triple function, viz., first, the titanium alloys with the steel with greater readiness if aluminum is present; second, the titanic acid which is formed in the molten bath is difficult of fusion, as is alumina, also produced by the addition of aluminum to a bath, but when both are introduced together a titanate of aluminum is produced which is more readily fusible; third, the aluminum serves the purpose of deoxidizing the steel before the titanium is brought into action, and the titanium is not called upon to do the work of rough deoxidation which the aluminum is better able to do.

The Goldschmidt product has the following average analysis:

Silicon	1 to 1.5 per cent.
Titanium	25 per cent.
Carbon	*nil*
Manganese	*nil*
Aluminum	5 to 6 per cent.
Phosphorus	0.05 per cent.
Sulphur	0.01 per cent.
Iron (by difference)	balance

Cupro-titanium.—Cupro-titanium is manufactured by the Rossi process, and calls for the reduction of rutile in a bath of aluminum to which copper has been added for the purpose of

[57] "Titanium in Iron and Steel," *Trans. Amer. Electrochem. Soc.*, 1911, vol. xx, pp. 265–279.

alloying with the reduced titanium. The method is otherwise the same as the process for the production of ferro-carbon titanium. Of course, ilmenite cannot be used as a source of the titanium, as the product can contain no iron. Experiments are still in progress to improve and reduce the cost of producing cuprotitanium, and the alloy has not as yet been exploited in the commercial field to any degree.

Mangano-titanium.—This is a titanium alloy brought out by the Goldschmidt interests for use as a deoxidizer in bronze practice. The alloy contains from 30 to 35 per cent. titanium.

B. INCANDESCENT MEDIA.—One of the most important uses to which both metallic titanium and some of its compounds have been put is for incandescent media for illumination. Certain of the titanium compounds have been employed in the manufacture of arc-lamp electrodes, of filaments for incandescent lamp use, and of gas mantles. The worth of the metal, either elemental or in the form of some of its compounds, in this field, is directly due to their elevated fusion and vaporization temperatures and to their radiation efficiency. The General Electric Company, at its Schenectady works, carried on extensive experiments for a number of years with material for arc-lamp electrodes. The results,[58] which were withheld for commercial reasons for a number of years, showed that substances containing titanium gave the highest efficiency. In 1890 the first patent in the United States was procured, calling for the use of a titanium compound in arc-lamp electrodes, while prior to this date (1878) Thomas A. Edison secured an English patent for the use of titanic oxide for the same purpose. Rutile has been employed to a considerable extent in recent years in arc-lamp electrode work, and it is claimed that such electrodes are superior to carbon electrodes, particularly for street lighting. The one disadvantage is that they cannot be used on alternating-current systems. A patent was procured in 1907 [59] for an arc-light pencil consisting of a metallic titanium alloy, as ferro-titanium. The light is yellowish to white in appearance. Still more recently a large number of patents have been secured calling for the use of titanium carbide. Electrodes made of titanium carbide, either

[58] Weedon, W. S., "The Titanium Arc," *Trans. Amer. Electrochem. Soc.*, 1909, vol. xvi, p. 217 *et seq.*

[59] U. S. Patent No. 840,634.

alone or admixed with other materials, have found some application, and a great deal of time and research has been expended with the work. These electrodes in action are comparatively free from the unpleaasnt hissing of the carbon electrodes, and they are further very steady and more durable.

Besides the compounds already mentioned, titanium suboxide has been used in electrode manufacture. The question of titanium for use in arc-lamp electrodes has been treated most particularly by Weedon, Ladoff,[60] Little,[61] and Barrows.[62] Titanium has been employed in the filaments of incandescent lamps of late, but these filaments as yet have not found widespread application because of technical difficulties connected with the manufacture of the wires. There is considerable paucity of data on this particular subject because of the commercial aspect of the business, and it would not be surprising if the results were withheld for as long as those pertinent to the use of titanium in arc-lamp electrodes.

C. MORDANTS AND DYES.—For use in the dyeing industry, titanium was first exploited in England. In general, the *ous* salts of the metal are powerful mordants which produce brilliant and stable colors. The company first interested in the work produced titanium ammonium oxalate from rutile by a complex and costly process which defeated the object in view. A number of titanium salts have been tried, but titanium potassium oxalate ($TiOC_2O_4$, $K_2C_2O_4$. H_2O) is the only one used extensively in the dyeing and textile industries. The compounds of titanium which have been successful find application as mordants and dyes for wool, cotton, and mixed goods, as well as paper. Titanous chloride ($TiCl_3$), titanous sulphate ($Ti_2(SO_4)_3$), and a double sulphate of titanium and sodium ($Ti_2(SO_4)_3$. Na_2SO_4. $5H_2O$) have been produced. The first two have found application in the textile industries and are manufactured on a large scale both in this country and on the continent of Europe. Salts of titanium have also been used in dyeing leather for shoes, and do not embrittle the leather as is the case with salts of iron.

[60] Ladoff, Isador, "The Titanium Arc," *Jour. Ind. and Eng. Chem.*, 1909, vol. i, No. 10.

[61] Little, George M., "New Developments in Arc-lamp and High-efficiency Electrodes," *N. E. L. A.*, Washington meeting, 1907.

[62] Barrows, W. E., *Electrical Illuminating Engineering.*

D. REFRACTORY COLORING MATERIAL IN CERAMICS, ETC.—Rutile is employed in the porcelain industry to produce a fine yellow color, the shade of color imparted depending upon the amount used. Rutile, because of its relative cheapness, has therefore supplanted uranium compounds, which are too expensive for commercial use. The mineral also finds application in the manufacture of artificial teeth to produce the color desired for matching. In dental practice, when artificial teeth are to be mounted, the teeth adjoining are matched with standard-colored teeth. Rutile gives the desired shade and, in the paste from which the teeth are moulded, varies from 0.5 to 4 or 5 per cent.

E. MISCELLANEOUS USES.—Titanium compounds have some other limited uses not already mentioned, as follows: Rutile crystals have been used for gems in jewelry mountings. Titanium nitride has been proposed as a basis for nitrogen and fertilizer manufacture, but has not been employed commercially as yet. Titanium dioxide has found application as a protective paint for iron and steel, while the sesquioxide (Ti_2O_3) and its salt derivatives have been employed in textile work as reducing agents. Other uses are instanced in the technical press, but are of not sufficient note to record here.

6. TITANIUM IN THE METALLURGY OF STEEL.

General Statement.—The important question arises: Has titanium really any influence on the properties of steel? The question [63] has been invariably answered in the affirmative by authorities because of the incontrovertible evidence brought out by actual experiment and that gleaned from the probably trustworthy literature on the subject. For some reason or other, there unquestionably exists considerable skepticism. It is the purpose of the following paragraphs to collate the more authoritative thought regarding the matter in order to demonstrate that the addition of titanium to steel has an important influence on its properties, and that its use is to be recommended to steel makers who have any regard for the quality of their product.

Titanium in the form of one of its ferro-alloys is used rather widely at present, and its use tends to increase, although there has been some falling off in its employment for the treatment of

[63] Fitzgerald, F. A. J., "Has Titanium Any Influence on the Properties of Steel?" *Met. and Chem. Eng.*, January, 1915, vol. 13, p. 28.

Bessemer-rail steel. As a final deoxidizer and denitrogenizer in the metallurgy of steel, it follows the usual treatment for these objects with ferro-manganese, or spiegeleisen, and ferro-silicon. Leading metallurgists seem to agree that titanium achieves its remarkable results through its strong deoxidizing powers, together with its effect of giving the slag sufficient fluidity to completely separate it from the metal. The presence of titanic oxide (TiO_2) lowers the fusion point of occluded slags in iron and steel and thereby imparts the fluidity which will account for their elimination.[64] The statement that occluded oxides and gases, such as ferric oxide (Fe_2O_3), ferrous oxide, (FeO), free oxygen and nitrogen, etc., are undoubtedly the real causes of many of the difficulties of steel makers needs scarcely be made. A great deal of data has been secured pertinent to the disastrous effects of sulphur and phosphorus; that the effect of the former has been overdrawn is demonstrated by the recent work of Unger[65] and Hayward.[66] In fact, many metallurgists have agreed for years that the harmful influence of sulphur was indeed mythical at times; *i.e.*, within certain limits. The fact, however, that both occluded oxygen and nitrogen in steel reduce its static strength and dynamic properties, and otherwise injure it, has been definitely shown. The feeling is that free oxygen and oxides are more harmful to steel than either phosphorus or sulphur within certain quite wide ranges. The investigations regarding the presence and effect of nitrogen are incomplete, and the results, therefore, are uncertain. The presence of nitrogen to the extent of 0.02 to 0.025 or 0.045 per cent. in certain steels is enough to cause them to break asunder, destroying all elongation and reduction of area.[67] Some experiments made in the research laboratory of a mid-western steel plant[68] showed that certain large percentages of nitrogen could be readily incorporated into ingot iron, and that there occurred a resultant great brittleness of the metal; in fact, in some cases the iron could be pulverized in the fingers.

[64] Stoughton, B., U. S. Pat. Office, Proc. Ser. No. 463,610.

[65] Unger, J. S., "High and Low Sulphur in Basic Steel," *Iron Age*, January 13, 1916, p. 146.

[66] Hayward, C. R., "The Effect of Sulphur on Low-carbon Steel," *Bull. A. I. M. E.*, October, 1916, p. 1841 *et seq.*

[67] Le Chatelier, H., Paper, Congress of Metallurgists, Belgium, 1905.

[68] Private communication, June, 1916.

The great affinity of oxygen and titanium is an absolutely sure method for completely deoxidizing a steel, the advantages of which need no elaboration. It has been proved that an ingot of steel containing a very little titanium will be practically free from segregation.[69] Bessemerized and Tropenas-converted steels are known to contain the greatest percentage of occluded oxides and gases, with open-hearth, crucible, and electric-furnace steels following in the order named. The reason for this lies in the mode of manufacture. Titanium has a strong chemical affinity for oxygen and will remove traces of it from the metal, which otherwise do not yield to the ordinary deoxidizers with their concomitant carburizing reactions. Its apparently unique property of removing occluded oxidized substances by causing them to separate more readily avoids the most harmful effects common to steel products. Titanium, in removing nitrogen, is one of the very few elements which attacks this relatively inert gas. The fact that titanium tends to lessen segregation of steel ingots may well be believed because of the well-known influence in this respect of agents which deoxidize and thus quiet a wild metal.[70]

Until recent years titanium was regarded as a rare metal; its use, although it was known to be one of the most potent of deoxidizers and denitrogenizers, was prohibited, by reason of high cost, until the exploitation of the ferro-alloys. These alloys, as already stated, are produced by two different methods: first, the electric-furnace process of A. J. Rossi; and, second, the aluminothermic process of Dr. Hans Goldschmidt. The function of the alloys made by both processes is the same. Titanium appears to exert little direct effect on the constitution or structure of the steel itself. Although it lowers the Ar_3 point, it has little influence on either Ar_2 or Ar_1, and steels with as much as 10 per cent. Ti exhibit the normal pearlitic structure of straight carbon steels. Besides its use as a superpurifier for rail steel, titanium is finding application in the treatment of steel and iron rolls where resistance to abrasion and shock is thereby said to be increased; for steel castings in foundry practice; for both low and high carbon steel chain; for gears, pinions, tires, die plates and heads, propeller shafts, driving rods and other forgings; for tool and automobile steels; for cast-iron ingot moulds; for acid pots, and

[69] Von Maltitz, E., *Stahl und Eisen*, No. 41, 1909.

[70] Waterhouse, George B., *Proc. A. S. T. M.*, 1910, vol. x, pp. 201–211.

chilled-iron car wheels. It is also said to improve the qualities of nickel and chromium alloy steels, as well as manganese steel. The use of titanium in small quantities in manganese steel, in particular, promises to give results of great value. Manganese steel containing 11 per cent. Mn, one per cent. C, and a small amount of titanium—up to 0.40 per cent.—is readily forged and rolled and can be machined with comparative ease. Such steel is extremely hard, and yet very strong and tough, having a tensile strength of from 65 to 70 tons per square inch and an elongation of 45 per cent. on a 2-inch length.

How Titanium is Used in Steel Metallurgy.—The modern method of employing titanium as a final deoxidizer and denitrogenizer is to augment the incomplete cycle, after the other deoxidizers have been added, by using one of the ferro-titanium alloys. The other deoxidizers may be added either in the furnace or in the ladle, but it is best that the titanium alloy be added in the ladle, and, further, that time be given for the titanium to complete its clarifying action. Thus the ladle will be held for five to ten minutes before pouring, so that the entrained slag formed may have time to rise to the surface. There is no opportunity for the bath to chill by thus holding it, because the titanium action is exothermic, the temperature of the metal being appreciably raised. Titanium, by combining with oxygen with the production of titanic oxide (TiO_2), has a heat of formation of 218,000 calories. The cost of treatment of steel with ferro-carbon-titanium (the Rossi product) varies from about 25 cents to $2 per ton of metal treated. It is the cheapest deoxidizer above the grade of ferro-manganese or ferro-silicon. At the prices which ferro-manganese has reached in the past year (*i.e.*, from $200 to $450 per ton, tidewater) it is a cheaper deoxidizer, when it is considered that American steel makers use about 19 pounds of the manganese alloy per ton of steel produced. The amount of the titanium alloy to be added is normally very small and should be proportioned according to the amount of impurities present.

A broad dictum says, "Make the steel in the furnace." The deoxidation of the steel is best performed in the ladle. Regarding the addition of the titanium alloys, these are best added to the ladle of steel after tapping from the furnace and before the slag has begun to run. For open-hearth steel, the supply of alloy

is placed at a convenient spot and, at the proper time, shovelled in. For soft mild steel, an addition equivalent to about 0.03 per cent. of titanium is enough to do the work required, under normal conditions. In general, larger amounts effect increased benefits, but, in the case of the carbon-bearing titanium alloy, they cannot be added because of the introduction of too much carbon thereby, and also because of the density imparted to the steel, which increases in proportion to the alloy addition and consequently is not always desirable. In the case of high-carbon steels, the increased density is more often desired and larger amounts of the alloy can be used.

In Lackawanna practice in making open-hearth steel, ferro-manganese and ferro-silicon are added to the ladle, as is normal practice in the United States. These alloys are added as soon as the ladle bottom is covered with hot metal from the tap, and the titanium-alloy addition follows as soon as possible. As already mentioned in the preceding paragraph, the titanium addition is to be made before the slag begins to run, otherwise it is difficult for the alloy to get down through the slag covering on top of the bath. The same thing is true for ferro-manganese and ferro-silicon also—the essential requisite is to incorporate the alloys with the steel and not with the slag. Further, the titanium alloy must not only be thoroughly incorporated with the metal bath, but it is highly important that sufficient time be allowed for the chemical changes to take place. The oxides that are formed, and the different gases or compounds, or whatever they may be, must be given time to separate from the steel and rise into the slag. What has just been said for open-hearth practice applies in general to Bessemer-converting practice. In the latter, the spiegeleisen and ferro-manganese are added to the converter; then, as the steel is being poured into the ladle, the titanium alloy is added; the ladle is then held for a few minutes before teeming the steel into ingots.

In Bessemer Practice.—In the Bessemer process the titanium alloy should be shovelled into the stream of metal which is being poured into the ladle, the steel having been recarburized in the converter prior to pouring, as is normal procedure. Inasmuch as the titanium reacts vigorously with molten silicate slags, it is strongly recommended that it receive the maximum amount of stirring with the metal before much of the slag begins to run.

otherwise much of it will be wasted. In order to effect a churning and stirring of the metal so that the titanium alloy is thoroughly incorporated, it appears expedient to allow the molten stream to strike the ladle a little off centre, so that the bath receive a gyratory stir. After the alloy is properly mixed, it is best to hold the ladle for about three to five minutes so that the titanium may have time to complete its action and remove most of the dissolved oxygen, nitrogen, and entrained oxides and slag. The titanium alloy screened through a 0.125-inch screen and packed in convenient sized cans is recommended for Bessemer practice or for Tropenas converting.

(*To be continued*)

The Utilization of Pyrite Occurring in Illinois Bituminous Coal. E. A. HOLBROOK. (*University of Illinois Bulletin*, vol. xiv, No. 51, August 20, 1917.)—The mineral pyrite (or probably its name is marcasite) occurs in nearly all Illinois coals as characteristic brassy yellow colored streaks, thin plates, lenses, nodules, bands, or balls of all sizes, sometimes up to 10 or 12 inches in thickness. In the ordinary course of mining, pyrite is rejected as a deleterious impurity. When pure, pyrite contains more than 50 per cent. of sulphur, and when the nearly pure mineral is properly burned or roasted, the sulphur dioxide gas resulting forms the basis for the manufacture of sulphuric acid. In normal times the commercial supply of sulphuric acid is obtained as a by-product of the roasting and refining of zinc, lead, or copper ores, which contain sulphur. The prohibition against undue atmospheric pollution in the neighborhood of smelters, due to the formation of sulphur dioxide, has often made its recovery a matter of necessity not regulated entirely by market demands for the resulting sulphuric acid.

In normal times in the United States the market for pyrite has been irregular and has been limited to small areas near the points of production and utilization, owing to the fact that high freight rates have operated against extensive distribution. Moreover, Spanish pyrite has normally been imported easily and cheaply to the extent of a million tons or more per year, usually in vessels which would otherwise return to America in ballast. Since the beginning of the European war the supply of Spanish pyrite has been largely cut off, and under present market conditions (July, 1917) a clean pyrite product is worth three or four times as much per ton as the coal with which it occurs. A series of experiments conducted on a commercial scale has shown that, where pyrite occurs in sufficient quantities to justify its recovery, a 50-ton plant may be designed to serve a single mine or group of mines which will yield a profit of about $75 per day, or $1.50 per ton of raw pyrite, with an initial capital cost of about $18,000. The market for domestic pyrite is active and prices as high as $8 per ton are offered.

DEVELOPMENT AND PROGRESS IN AVIATION ENGINES.*

BY

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THE art of aviation and the industry of building airplanes, engines, and accessories, to meet the demands of the art, are now going forward with wonderful strides. Commercial usage as well as war usage begins to attract the attention of the aeronautic engineer.

It is interesting to refer back a few years to the JOURNAL OF THE FRANKLIN INSTITUTE, dated October, 1910, and learn to appreciate the rapidity of change in the art. Reference is made therein to a "useful load of 450 pounds, including three passengers." This weight is the equivalent of about 75 gallons of gasoline, which is less than the amount required for four hours' flight of a two-passenger airplane of recent design and construction. Nearly twice this volume of gasoline is now carried, with two passengers and 150 pounds additional useful load.

Reference is made to airplane flying altitude: "Prominent aviators who undertake a cross-country flight select their course with care and maintain a very high altitude." "Lambert, who ordinarily does not seek high altitudes, in soaring over Paris, was obliged to ascend to a height of more than 1600 feet." In the war zone danger is now imminent below 16,000 feet altitude. Much flying is necessary at greater altitudes. Peaceful cross-country flying is done at what are now called safe altitudes of from 3000 to 7000 feet. From such altitudes it is probable that a suitable landing area could be reached in case of need. With a "dead" engine the angle of glide is about six to one. This means that a six miles radius circle is available for a choice of landing from an altitude of one mile.

Duration of flight is referred to as follows: "Present-day flights are no longer measured in minutes." "The hour has been exceeded by many pilots." "The aëroplane will enter the

*Presented at a meeting of the Mechanical and Engineering Section, held Thursday, March 1, 1917.

field of touring." All this and more is now true after a period of six years.

Aviation engine weight per horsepower delivered has not changed much; but engines are more reliable, more efficient and stronger, and heavier where experience has taught the need. The term "weight per horsepower" is a loose one. There are many parts that may or may not be considered as a part of the engine of the power plants to be included in the weight. Some twenty-eight or thirty items have been found in this doubtful class. The weight

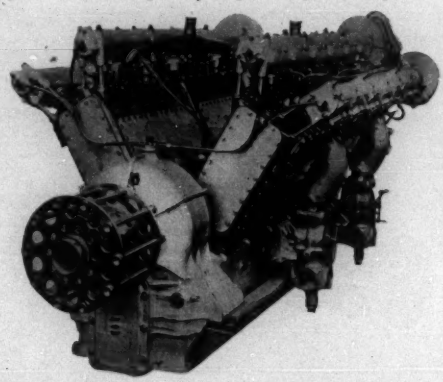
Reconnaissance airplane and pilot (Carlstrom) that made Chicago-New York flight. (Curtiss Model JN4.)

of gasoline and oil consumed per hour is figured by some as an element of engine weight. It does influence the design of the airplane as a whole. It must be known. For example, the rotary, air-cooled engine, although very light, about two pounds per horsepower, is outclassed by heavier engines if the airplane must fly more than three hours. The rotary engine consumes too much gasoline and oil per horsepower-hour for long flight.

Broadly speaking, it may be said that the weight may safely vary from two to five pounds per horsepower. This will include the weight of magneto, carburetor, and wiring. Other elements

of the power plant, such as water, water piping, oil in the engine and the propeller, are not included.

An engine which ranks very high for speed, climbing, and endurance weighs 2.4 pounds per horsepower. This engine is high strung and delicate, but very effective. Many types of engines are in practical use. There is an ever-changing idea as to the proper function for each type, and a constant shifting of opinion of one engine to another of any given type, as to the superiority. Any improvement of design, material, or workmanship may result in temporary superiority. Competition in this



Sterling-Sunbeam 300-horsepower engine, 12-cylinder, V type.

matter is keen. All sorts of daring expedients are tried under war pressure. The result is rapid change and rapid improvement.

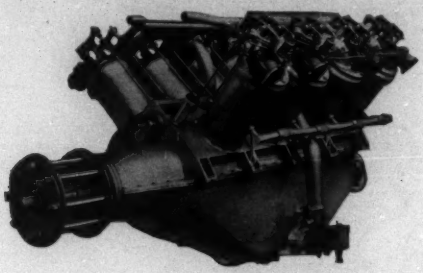
The future one may not predict. The probable status six months hence is only speculation. It is certain that greater horsepowers are appearing for all types and sizes of airplanes. The result is increased speed, climb, and load-carrying capacity. There seems to be no limit to this increase except that imposed by lack of experience. This lack is being made good very rapidly just now by war conditions.

About a year ago it was thought that no more than 90 horsepower could be obtained from a radial rotary, air-cooled engine. One-third more has been obtained, and nearly double is now planned.

Similar improvement is being brought about, by experience, in other engines. An eight-cylinder, V-type engine now develops consistently 210 horsepower. Six months ago it did not function as consistently at 180 horsepower. There has been no radical change of design or size.

Experience has been the teacher. No internal-combustion engine of new and extreme design can be brought to a condition of practical excellence in less than a year, and often two years. Yet partially developed engines must be purchased and used or there will never be complete development.

The next, and very important, step is the development of organizations that can really manufacture an aviation engine or airplane, rather than build a few models, or a dozen or two nearly



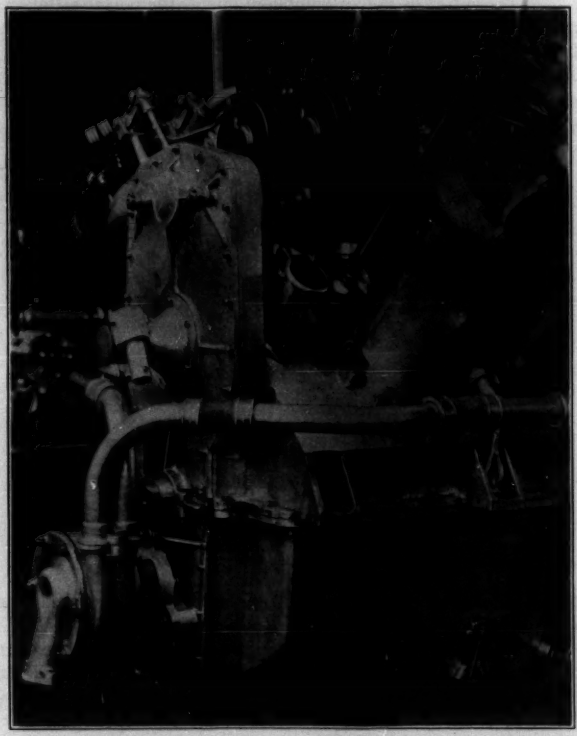
Curtiss V 2, type 3, 200-horsepower engine, 8-cylinder, V type. Front end.

alike. This is a task that will easily occupy another year of consistent endeavor. At least one aviation manufacturing organization finds itself in this state of development. The building nucleus of men must be expanded into a manufacturing force. The product must be adapted to practical methods of manufacture, to existing tools, and standards, so far as possible. Otherwise no quantity production may be expected.

This has been proved many times in other industries. The aircraft industry is not different. In fact, it is astonishingly similar to the motor-car industry as found during its beginning and early growth.

Perfection would be approached by having each plant producing aviation material, as engines or airplanes, so organized and equipped as to manufacture one type only and do that well.

This condition will be brought about by a consistent demand or in response to a pressing need. A proper foundation for such a development is now being laid by the same engineering body that assisted in the amazing growth of the motor-car industry—The

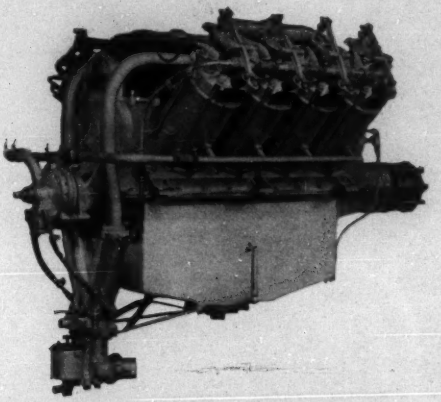


Curtiss V2, type 3, 200-horsepower engine, 8-cylinder, V type. Rear end.

Society of Automotive Engineers (recently Automobile, but expanded to include closely-allied industries, of which aviation is one). Its standards and engineering practices will creep into the new industry as they did into the older one.

It is difficult to discuss aviation without mentioning the Wright Brothers. They developed much knowledge of flying without an engine by gliding experiments, and then sought an engine.

At the outset of the automobile industry the power estimated as necessary was too small. Practical tests indicated that three horsepower would suffice, with a generous factor of safety. History repeated itself. Orville Wright recently stated that an eight-horsepower engine was figured as necessary. Such an engine, not to exceed 200 pounds in weight, was sought in the



Curtiss OX 100-horsepower engine, 8-cylinder, V type. Rear end.

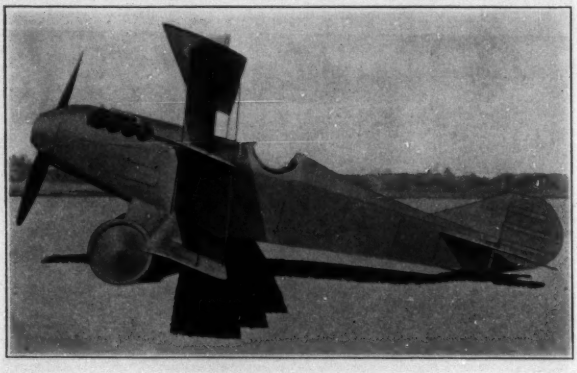
open market. This occurred in 1903, and none was offered that was worth considering.

The Wrights then built a four-cylinder 4 x 4-inch engine that did weigh less than 200 pounds. This engine developed 12 horsepower and actually flew an airplane. This engine was followed soon by a much better one that developed 30 to 35 horsepower. It was simple in the extreme degree. A jet nozzle in the intake pipe served to atomize the gasoline; the ignition was a low-tension system; the water jackets were of sheet aluminum, the crank shaft very small in diameter, as were all other moving parts. Later engines of the same design have produced

more power, are very efficient, and still being used to a limited extent.

The four-cylinder vertical engine was the first aviation engine to do real service. The airplane flown with so small an amount of power was large in wing area for the load carried, slow in speed, and sluggish in movement, judged by present standards. Such an airplane resembles the butterfly rather than the swallow. It is not like the successful fighting machine, yet will surely find place for peace usages.

Closely following this first type of engine came six-cylinder vertical and eight-cylinder V engines of 65 horsepower and 75



Curtiss model S3 triplane speed Scout.

horsepower. All of these were too light and frail for hard service. Minutes of flight were possible, but not hours, as now required. High-pressure lubrication to vital parts had not been developed. Valves failed because of inadequate cooling and material.

In August, 1908, the Wright Brothers made their first flight in France. Following this date, the French engineers developed airplanes and engines of various types that embodied the fundamentals demonstrated by the Wrights, so far as the airplane was concerned. The scientist contributed much to the art by working out the theory of the art of flying. A long step forward was taken in the succeeding years.

Air-cooled engines of the radial rotating form were developed, then air-cooled and water-cooled vertical and fixed cylinders These successive steps again repeated the steps taken by those who had developed the automobile and its engine: all were too frail and of small power. It seems safe to state that nothing as large as 100 horsepower was reached or thought necessary. The Gnome radial rotating engine became most successful, and, as experience improved the skill of the aviator, the power of the engine grew gradually from 60 horsepower up to 90 horsepower.

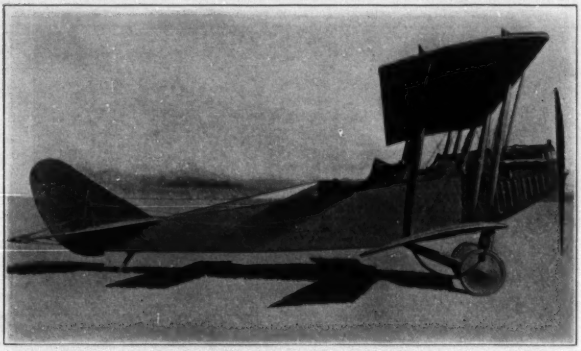
Comparison between reconnaissance biplane (Curtiss model JN4) and triplane scout (Curtiss model S3).

Similarly the speed of the airplane increased up to 60 or 70 miles per hour, with slow speed or landing speed in the neighborhood of 40 miles per hour.

After a few years of this normal development, with reasonable progress relatively slow because of the enormous cost attending aircraft experiment, came the present European war. Then began a feverish and rapid development, during which rash moves were made and long chances of an engineering character were taken. How much the demands of war have advanced the art of aviation can only be guessed, but surely as much as a generation.

As soon as the absolute necessity of aircraft as a part of a modern army was demonstrated, the production of them was forced to the limit.

Extreme types are built and flown. Planes of small area, equipped with engines of large horsepower, which must be landed at 80 miles per hour, must be used. This type is the fighting craft that seeks altitudes above the hostile projectile danger zone (about 18,000 feet), and higher yet in order to be able to swoop down on the slower plane or upon some less skilful aviator. One hundred horsepower is no longer enough for this light and agile airplane. An engine, eight-cylinder, V type, of 150 horse-



Curtiss model JN4P military tractor.

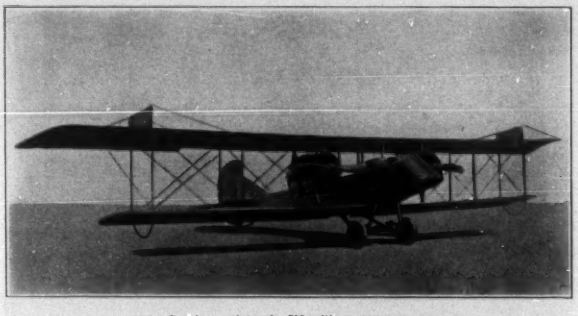
power, is most popular now, but with a tendency toward, and small actual use of, 200 horsepower, yielding a speed of 140 miles per hour and a climb of more than 1000 feet per minute.

The only type of airplane used for war purposes, satisfied by an engine of 100 horsepower or less, is the school machine, which carries teacher and student, tandem or side by side, in the body. Thousands of these are needed and being used in Europe. It is pleasing to know that one engine being built in the United States is giving excellent satisfaction in England for this purpose.

For large warcraft, battleplanes so-called, more powerful engines are used. So far as known, this demand is met by

engines of 250 to 350 horsepower. These aircraft carry bombs or explosives up to 1000 pounds in weight, and small defensive guns. They are not agile nor fast, and are defended by fast machines, when possible to do so. They are the battleships of the air, defended by the torpedo-boat.

To produce this power, 12 and 18 cylinders are used. The latter is of the V type, with three rows of cylinders in place of two. It is new and said to be very successful. The power is transmitted to the propeller through gears, the propeller rotating about three-fifths engine speed, at about 1000 to 1200 revolutions per minute. Wherever possible, gearing is avoided because of the great weight added and increased mechanical difficulties. The



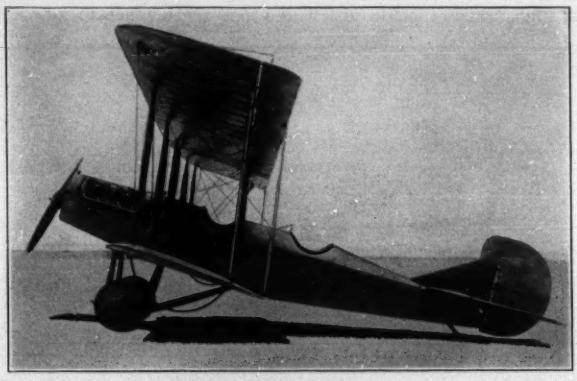
Curtiss model twin JN military tractor.

difficulties surrounding the propeller problem also deter. The combination of much power and high speed tends to wreck propellers. There are many elements entering into this phase of the use of large powers not yet fully understood.

An obvious means to equip an airplane with more power is to use more than one engine unit. This is done and will be done, but there is a penalty attached to the plan. The ideal disposition of weight in an airplane is to have all concentrated at the centre of gravity of the entire structure. A single engine unit approaches this condition as nearly as may be. Two units mounted out in the wings, away from the centre of gravity, increase the inertia, decrease the agility and manœuvring quality very much. An airplane so equipped cannot quickly turn and twist to avoid the attack of the fast machine.

There will come a time when all engineering attention is not drawn to airplanes for war purposes. Then a type of plane will be developed that will not have speed, agility, and climbing power as its principal attributes. Much less power will fill this need, and a much more normal aircraft will result. Then the multiple-unit plane will have a chance to develop.

Our present aircraft development is what the racing car has been to the automobile industry—a wonderful developer for normal product and usage. In time real manufacture will begin, prices will drop and popularity increase. Engines to meet such a purpose will develop rapidly. They will, as now, be



Curtiss model R4 military tractor.

highly refined as to their essential functions, but of ordinary construction as to the non-vital functions. At present the extreme of design, workmanship, and material is the aim for all parts. The art is too young to permit any other procedure.

ENGINE DESIGN.

The desired engine must be light but it must be reliable. It must be capable of continuous operation at very nearly full capacity for long periods. A 20,000-foot climb requires that everything shall be perfect.

The periods of partial use and rest are short, as for a glide. The period of level flying is from 75 per cent. full power to full

power, at the desire of the operator. Pursuit or flight means full power, patrol or observation duty means less; but at no time does the usage approach that of the motor-car engine. The demand is even greater than that on the marine engine, which carries a very constant load; but the marine engine may be made heavy—the aviation engine must be light.

Experience has taught that lightness must be abandoned in favor of stiffness and strength for all vital parts, such as crank-shaft, crank-base, main bearings, crank-pin and piston-pin bearings, and that all possible lightness must be gained by hollow construction in combination with materials most carefully chosen. Coupled with these features must be found most thorough oiling at high pressure, with oil led in a positive manner to all vital

Curtiss model twin JN seaplane.

points. Much experimenting must be done, even after careful design, to arrive at a proper distribution of oil. Clearances, oil apertures and oil viscosity (hot) must be balanced.

Poppet valves must close on seats that are thoroughly cooled. Exhaust valves run cherry red hot at best. Proportions and detail of design must avoid warping and breakage.

Ignition is desired in complete duplicate for each cylinder. Magnetos must be coupled and driven in such a manner as to minimize vibration. Magneto difficulties have been of mechanical failure more than electrical, and the direct result of excessive strains due to rigid driving couplings. Wiring must be carefully conducted and fastened to prevent failure from chafing, following excessive vibration.

Spark-plugs have been the cause of more trouble and uncertainty than any other single item of aviation engine detail. The prime difficulty has been to keep the plug cool. A cool location must be provided in the design. The plug must not extend so far into the explosion chamber as to be seriously flame-swept, nor must it be deep in a hole or recess with delayed and irregular ignition. The plug itself must be gas-tight to prevent "blow by" and resulting overheat. The plug that satisfies the automobile engine will fail quickly under aviation service. This defect is more serious than appreciated, and must be guarded against. It is not easy to locate, as often assumed. Frequent change of plugs is now resorted to in the interest of reliability. Close

Curtiss model N9 seaplane.

attention to the foregoing and simple items will surely increase spark-plug life and engine reliability.

There is no more mystery about an aviation engine than about any other, when the real truth is known.

One hundred and fifteen pounds per square inch mean effective pressure is very hard to handle in connection with a light bit of construction. This pressure is needed to yield the horsepower per unit volume.

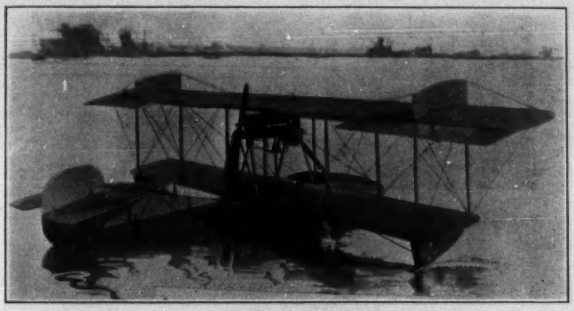
The perfect balance of moving parts is necessary. The airplane structure is very sensitive to vibration, and the occupants are seriously disturbed by an engine not functioning smoothly.

Perfect distribution of gas to give uniform explosions is a

requisite. The delicate engine structure fails rapidly under the influence of irregular impulses. Carburetor parts, thin aluminum castings, wiring, gasoline tanks and piping, magneto, radiator, and propellers all fail to a serious extent in the presence of vibration.

Simplicity of design, with the smallest possible number of parts, must be the aim. Each additional screw, joint, part, or accessory increases chance of trouble in the air. The failure of such detail may cause a forced landing accident—as surely as the failure of a vital part.

The fire risk may be minimized by such design of engine compartment as will promote the movement of a large volume of air



Curtiss model F flying boat.

in and out of the engine compartment—in such a way as to carry gasoline or gas clear of the airplane body and operator's cockpit. Without an accumulation of gasoline the danger is small.

ENGINE WORKMANSHIP.

The keynote of this feature is that quality must come first, cost second or last. Time must be taken to arrive at the desired accuracy or finish. Time and money must be spent to balance reciprocating parts. A limit of one per cent. difference of weight for all pistons and rods in an engine is required in some cases. Exact balance of all pairs is required.

Piston rings must be tight as the result of perfect fit and bearing. Many rings must be discarded to get perfect sets.

Rings good enough for motor-car engines will not do the work in aviation engines.

The engine must not throw oil from any joint, valve stem, gear-box, or pipe. Oil so thrown may easily cloud the goggles of the pilot. Only the closest of fits will achieve such oil-tightness.

Castings, whether aluminum or iron, must be true and of even wall thickness and of extreme lightness. Many rejections must be made to get the uniformity needed. Such rejections should be figured by those accepting engine casting orders. The best of pattern equipment and forging dies must be furnished for

Curtiss Aeroplane Company—Assembly floor, showing large flying boat.

a comparatively small number of pieces. This adds materially to the cost of a part, but is necessary to attain workmanship of aviation engine quality.

Machine tools, fixtures, and methods must be such as to produce absolute accuracy, regardless of cost. "Quality first" should be the watchword in aviation, not "Safety first," because high quality means safety.

It is very hard to create this atmosphere among business men, superintendents, foremen, and workmen, who have always been obliged to keep in mind the cost and selling price of a product

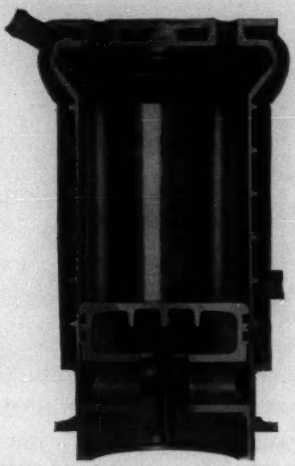
to meet competition. There is no competition in airplane engines yet. The art is too new. Performance comes first. Only the best in design, material, and workmanship will suffice.

It is possible that too much time and money are being spent; but at this time experience has not been great enough to be certain of this. Continued use over a long period of time will determine. During the youth of the industry is not the time to take a chance.

Quality and safety come first.

ENGINE MATERIALS.

Excellent material is required for a motor-car engine, which is rarely worked to anywhere near its limit of power. Take for



Cross-section of steel cylinder and aluminum piston, Curtiss V2, type 3, 200-horsepower engine.

an example a 40-horsepower engine. It runs quietly about over roads nearly level, with liberal lubricant for the work being done and consuming hardly 25 per cent. (10 horsepower) of its rated power.

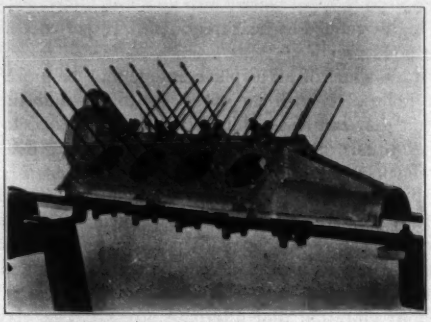
Under comparable conditions an airplane engine uses 75 per cent. of its power. Lubrication must be perfect, not nearly so.

Further: a motor-car engine of 672 cubic inches capacity is given a normal rating of 65 horsepower. An aviation engine of

the same volume is rated at 154 horsepower. As a motor-car engine not over 25 per cent., or 16 horsepower, would be ordinarily used, but as an aviation engine not less than 75 per cent., or 114 horsepower, would be habitually used, a ratio of about 7 to 1.

In addition, the aviation engine is built as light as possible, say about one-half the weight for a given piston displacement. Roughly speaking, this represents a punishment of material within the aviation engine 14 times as severe as that in the motor-car engine.

The present life of an aviation engine indicates severe punishment. Up to the time when a complete overhaul is necessary this



Upper half of crank-case for Curtiss OX 100-horsepower engine.

life is about 50 hours at, say, 100 miles per hour, or a total of 5000 miles. A motor-car engine runs about 25,000 miles up to the time when an overhaul repair is necessary. The speed cannot average over 25 miles per hour. This means 1000 hours' operation, or 20 times that of the aviation engine.

A severe test of endurance for the motor-car engine under shop or laboratory conditions, and where destruction of the engine is invited and closely approached, is under a development of power of about 0.15 horsepower per cubic inch displacement. It is considered a fine performance for a stock motor-car engine to last 300 hours under this load. The aviation engine must do not less than this at any time and with 100 per cent. score. Otherwise the engine is not a successful aviation engine.

These are rough comparisons, but they show the relative severity of work. To meet these severe conditions the very best of steel for each engine part must be used. "Best" means that money must not hinder, but high-priced steel is not sure to be best. The highest of technical skill must be utilized: first, to select the steel from chemical and physical soundness standpoints; second, to treat it in such a manner as to give the best possible endurance and the highest elastic limit consistent with the possibility of machining. Here, again, money must not be a consideration. Slow methods may be necessary to work the material.

The crank-shaft of a motor-car engine is usually so large and heavy as to permit the use of steel having an elastic limit of about 70,000 pounds per square inch and with a physical structure not very highly refined by heat treatment. Experience has shown this to be good practice.

The crank-shaft of an airplane engine may be more in diameter, but hollow to such an extent as to demand the highest elastic limit that can be machined, say from 120,000 to 140,000 pounds per square inch, with a reduction of area, denoting the highest refinement of grain, of 50 per cent. or more.

The lighter parts of a motor-car engine, such as valve rocker arms, are given a toughening treatment for a fair forging steel, say 60,000 to 80,000 pounds per square inch elastic limit. The rocker arms of an airplane engine are so light and delicate as to require a fine alloy steel most carefully treated to give resistance to vibration and alternate stress. The elastic limit should also be in the neighborhood of 130,000 pounds per square inch. This, coupled with hardness at certain points, brings additional care and expense.

The highest intelligence and widest experience are needed to arrive at the proper combination of hardness and toughness and endurance. Experimental work to the point of actual failure is necessary to arrive at the extreme limit of endurance. In the aviation engine the extreme is sought.

A decade hence there will exist an accumulation of empirical knowledge. Extremes will then be less common or else the extreme of to-day will be the commonplace of the future. Experience will repeat in aviation as in many other industries and arts.

(Illustrations for this article were obtained through the courtesy of The Curtiss Aeroplane Company and Sterling Engine Company.)

PHYSICS OF THE AIR.*

BY

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Professor of Meteorological Physics, United States Weather Bureau.

CHAPTER VII.

ATMOSPHERIC CIRCULATION.

INTRODUCTION.

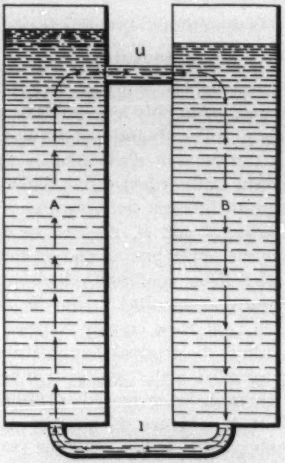
ATMOSPHERIC circulation, whether manifesting itself in a monsoon, for instance, or in only a gentle lake breeze, is a gravitational phenomenon induced and maintained by temperature differences. This can be well illustrated by the flow of water between two adjacent tanks when connected by an upper and a lower pipe and kept at different temperatures.

Let the two tanks, *A* and *B*, Fig. 25, be filled to the same level slightly above the upper pipe *u*, and let them have the same temperature. Under these conditions there will be no flow of water from either tank to the other. Now let the pipes be closed and let the water in tank *A* be equally warmed throughout. It will expand, providing its original temperature was not below 4° C., and the amount of water above each level in *A*, at and below the initial surface, be increased in proportion to its distance from the bottom. Hence the pressure due to gravity is everywhere throughout the original volume correspondingly increased—the maximum increase being at the level of the initial surface. If the lower pipe *l* be now opened, there still will be no flow of water from either tank to the other. But if the upper pipe be opened, water will flow from *A* to *B*, and in so doing will decrease the pressure on all parts of *A* and increase it on all parts of *B*. If *l* is also open, water will flow from *B* to *A*. If both pipes are left open and the water in *A* kept constantly warmer than the water in *B*, there will be continuous circulation of the water from *A* to *B* through the upper pipe and from *B* to *A* through the lower. Obviously the same results could be obtained by applying a cooling process to *B* instead of a warming one to

* Continued from page 408, vol. 184, September, 1917.

A. That is, since the circulation in question is a gravitational phenomenon induced by a temperature difference between the water in the two tanks, it clearly is immaterial how this temperature difference is established, whether by heating the one tank or by cooling the other. Similarly in the case of the atmosphere. If two adjacent columns of air, or the masses of air

FIG. 25.



Circulation between warm and cold tanks.

over two adjoining regions, whether large or small, are kept at different temperatures, there will exist, through the action of gravity, a continuous overflow from the warmer to the colder, and an underflow from the colder to the warmer. Neither does it make any difference in this case how the inequality of temperature is established and maintained, whether by heating the one section or by cooling the other.

VERTICAL CONVECTION OF THE ATMOSPHERE.

General Considerations.—Vertical convection of the atmosphere may be divided into two classes: (*a*) mechanically forced convection, as the rise of air on the windward side of a mountain

or other obstruction and its fall on the leeward side; (*b*) thermal convection. The latter, involving both warming and cooling, is by far the more important; in fact, it either constitutes or is associated with all natural air movements. It commonly is said to consist of the rising of warm air and the sinking or flowing in of cold air to take its place; but, while this describes the phenomenon of thermal convection, it seems to imply the false concept that warm air has some inherent ascensional power, whereas, in reality, thermal convection is only a gravitational phenomenon, consisting in the sinking of relatively heavy air and the consequent forcing up of air which, volume for volume and under the same pressure, is relatively light.

The terms "heavy" and "light" are used here advisedly instead of "dense" and "rare," because it is the relative *weights* of two adjacent masses of air of equal volume under the same pressure and not their *densities* that determine which shall fall and which shall be raised.

Three factors enter into the question of weight per unit volume when pressure is constant: (*a*) temperature, (*b*) composition, and (*c*) horizontal velocity, including speed and direction. The first of these weight factors varies widely and is very effective. A change in temperature by any given amount $\mp t$, say, changes the original weight per unit volume, W_1, to the new weight, $W_1 \pm w$ in the ratio,

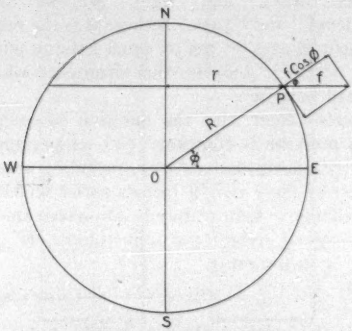
$$\frac{W_1}{W_1 \pm w} = \frac{T \mp t}{T} \quad \text{(Charles's or Gay-Lussac's law)},$$

in which T is the original absolute temperature. Thus if the original temperature is that of melting ice, and it is increased or decreased by 1° C., the weight per unit volume will be decreased or increased, respectively, 1 part in 273.

The effect of the second of the above weight factors, the composition of the atmosphere, is obvious from the following consideration: Since the number of gas molecules per unit volume under a fixed temperature and pressure is independent of the nature of the gas—Avogadro's law—it follows that under these conditions an increase or decrease of water vapor, say, in the atmosphere implies a corresponding decrease or increase of the other molecules present, mainly nitrogen and oxygen. Now the equivalent molecular weight of dry air is approximately 28.8

and that of water 18, hence a change in the water vapor, the only constituent of the atmosphere that appreciably varies, amounting to 1 per cent. of the total number of gas molecules present, alters the weight per unit volume by $\frac{108}{288}\ \frac{1}{100}\ W$, in which W is the weight of the unit volume of dry air under the same conditions of temperature, pressure, and gravity. On very warm days water vapor may amount to 5 per cent. or more of the total gas molecules present, and the air, therefore, be, roughly, 2 per cent. lighter than it would be if perfectly dry. Of course, changes from saturation to utter dryness, or the reverse, do not

FIG. 26.



Decrease of weight due to rotation of the earth.

occur in nature, but a variation of as much as 50 per cent. in the absolute humidity at a given place does occur through evaporation, condensation, and air movement. Hence on very hot days a change of 1 per cent. in the weight per unit volume of the lower air as a result of altered composition is quite possible without change of temperature. This produces a difference in buoyancy of the same order as that caused by a 3° C. change in temperature and therefore may be decidedly important.

The third factor that affects weight and convection, namely, horizontal velocity, while comparatively small, occasionally may be of some importance. Its numerical value can easily be computed. Let NS, Fig. 26, be the axis of the earth's rotation, and

let P at latitude ϕ be the point under consideration. The centrifugal force f acting on the mass m at the point P is given by the equation,

$$f = m\, r\, \omega^2,$$

in which ω is the angular velocity, and r the distance of P from the axis. Numerically,

$$\omega = \frac{2\pi}{86{,}164}.$$

Since the mean radius of the earth is about 6368 kilometres, and since weight equals mass times gravitational acceleration, or $981m$, approximately, in the C.G.S. system, it follows that at latitude 40°

$$f = \frac{w}{378}, \text{ roughly,}$$

in which w is the weight of the object considered, while the decrease, dw, in the weight, or the component of f at right angles to the surface, is given by the equation,

$$dw = -f \cos 40^\circ = -\frac{w}{493}, \text{ about}$$

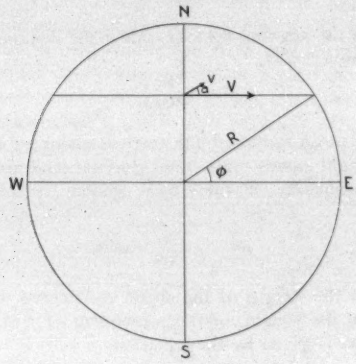
At latitude 40° a velocity of 22.4 metres per second (50 miles per hour) from east to west is equivalent to increasing ω^2 by 1 part in 8, approximately, and an equal velocity from west to east to decreasing it a like amount. That is, at latitude 40° a given mass of air in a west wind of 22.4 metres per second (50 miles per hour) weighs less than an equal amount in an east wind of the same velocity by about 1 part in 1972. Similarly for other latitudes in proportion to their cosines. Hence, other things being equal, an east wind tends slightly to underrun an adjacent west wind.

The above special solution of this problem may suffice for most purposes, but the following outline and conclusions of a more general solution probably will be of interest.

Referring to Fig. 27, let V be the horizontal velocity of the surface of the earth at latitude ϕ, v the horizontal velocity of the air with reference to the surface, α the angle between the east direction and the path, and assume the earth to be spherical and concentrically homogeneous. Further, let mg_0 be the gravita-

tional pull on the mass m, or the weight the mass m would have when at rest if the earth were nonrotating, and let mg be its actual weight. Then,

FIG. 27.



Change of weight due to horizontal velocity.

$$mg = mg_0 - m\frac{(V\cos\phi + v\cos\alpha)^2}{R} - \frac{m(v\sin\alpha)^2}{R}$$
$$= mg_0 - \frac{m(V\cos\phi)^2}{R} - \frac{mv(2\,V\cos\phi\cos\alpha + v)}{R}.$$

But, $mg_0 - \frac{m(V\cos\phi)^2}{R} =$ the weight of the mass m when at rest on the surface of the rotating earth. Hence, when the mass m is given a horizontal velocity v, its still-weight, W, is changed by an amount, ΔW, given by the equation,

$$\Delta W = -mv\frac{(2V\cos\phi\cos\alpha + v)}{R}.$$

Since the latitude is limited by 0° and 90°, it follows that the sign of the change (that is, whether the change consists of a decrease or increase from the still-weight) depends upon the value of α, or the direction of motion. Obviously whenever $\cos\alpha$ is positive, or the velocity has an *easterly* component, the change of weight is *negative*—maximum when ϕ and α are both zero, or when the motion is east on the equator. Similarly, since $2V\cos\phi$ is nearly always large in comparison with v, the change

of weight ordinarily is *positive* whenever the velocity has an appreciable westward component. This increase of weight clearly is a maximum when $\phi = 0°$ and $\alpha = 180°$, or when the motion is west on the equator.

Further, the direction of the wind in order that there be no change of weight is conditioned by the equation,

$$\cos \alpha = \frac{v}{2\ V \cos \phi}.$$

But, as above stated, $2\ V \cos \phi$ nearly always is large in comparison with v, and therefore the direction conditioned by zero change in weight commonly has only a small westerly component. For example, let $v = 44.7$ metres per second (100 miles per hour) and let $\phi = 60°$. Then, under these somewhat excessive conditions, for zero effect, $\cos \alpha = -\frac{1}{10}$, about, or the direction along which there is no change of weight is less than 6° west of the meridian.

From the above it appears that of the three factors that alter the weight of a given volume of air and thereby determine whether it shall rise to higher levels, sink to lower, or remain where it is, temperature is by far the most important, and horizontal velocity the least important. As a rule, the former alone need be considered.

Local Convection.—There are two distinct ways of thermally inducing convection: (*a*) by *heating below;* (*b*) by *cooling above.* Each is of great importance, both in general atmospheric movements and also in those restricted or local winds to which special names have been given. Where heating alone occurs the rising air does not return, but remains in equilibrium at its new level, where its final temperature is the same as that of the adjacent atmosphere. Similarly, when cooling alone occurs the sinking air does not again immediately rise. In other words, neither heating nor cooling, acting alone, can produce closed circulation in which the same mass passes through a complete cycle of positions, though, of course, a compensating movement must occur somewhere. A strong local uprush, for instance, except in the case of the thunderstorm, to be explained below, is nearly always compensated by a wide settling, so gentle that it cannot be measured. Similarly, restricted down-rushes of air, again except in connection with the thunderstorm, are compensated by wide and gentle upward movements.

Whatever the type of atmospheric disturbance under consideration, the most important general facts to remember are: that all vertical movements of the air are accompanied by dynamical heating or cooling; that rising air cools, roughly, at the adiabatic rate of about 1° C. for each 100 metres increase of elevation; that descending air warms at substantially the same rate; that dynamic cooling limits the height of upward convection; and that in many cases dynamic heating, and not the surface of the ground, limits downward convection.

CLASSIFICATION OF WINDS.

All the above is entirely general and of universal application. Gravity and temperature differences enter directly or indirectly into all atmospheric circulation, both the fundamental and continuous circulation that exists between the warm equatorial and cold polar regions, and those secondary circulations that occur only locally and occasionally. Nevertheless, clearness in any detailed discussion of all winds requires their grouping according to some basis of classification suitable to the purpose in view—in the present case a discussion of their initiating causes and modifying influences. Unfortunately, none of the current classifications of winds (*e.g.*, those listed in Milham's "Meteorology," p. 164 *et seq.*) is adapted to this end, and therefore a somewhat different grouping provisionally will be used.

Obviously no subdivision of air movements is possible on the basis either of gravitation or of temperature difference, since, as just explained, each is involved in every such movement.

But there also are modifying factors—friction, viscosity, turbulence, local heating, local cooling, deflection by mountain barriers, deflection due to the earth's rotation, and many others that make one circulation different from another in time of occurrence, extent, duration, direction, and intensity. Hence in considering the origin and nature of winds, it will be convenient to classify them as follows, according to the conditions that initiate or materially modify them, and to discuss separately, under its appropriate head, each distinct and well-recognized subdivision.

A.—Winds due chiefly to local heating—whirlwinds, cumulus convection, valley breezes, sea breezes.

B.—Winds due to local cooling—land breezes, mountain breezes, glacier winds, bora, mistral, Norwegian fallwinds, continental fallwinds.

C.—Winds due to simultaneous adjacent local heating and local cooling—thunderstorm winds.

D.—Winds due to widespread heating and cooling—gradient winds, monsoons, trades, antitrades, tropical cyclonic winds, extratropical cyclonic winds, anticyclonic winds.

E.—Forced winds, or winds caused by other winds—eddies, foehns (Chinooks), tornadoes.

WINDS DUE TO LOCAL HEATING.

Whirlwinds.

During clear, calm summer afternoons, particularly during a dry spell when vegetation is parched and the ground strongly heated, dust whirls often develop, and occasionally travel considerable distances before becoming dissipated. The flatter the region, the more barren, the hotter the surface, and the quieter the air, the more violent such whirls become. Hence, level deserts are especially frequented by such winds, amounting at times to violent storms, though never more than a few metres in diameter. The development of these storms in which convection is strong is not simple, but an understanding of them will materially help to an understanding of convection due to heating in less obvious cases.

It is well known that those regions in which violent dust or sand whirls occur are also the places where inferior mirages are most frequent. The reason for this coincidence is the fact that the density gradient of the atmosphere essential to the production of a mirage simulating a lake, namely, an increase of density with elevation, is most favorable to strong vertical convection. Under these conditions the air is in that same unstable equilibrium that applies to a column of liquid whose under layer is lighter than the upper—whose under layer is oil, say, and upper layer water.

At first sight it might seem that no such condition of considerable extent can obtain in nature; that as soon as the under layer became specifically lighter than the one next above, they would change places. Whenever a cork, for instance, is let go under water it bobs up. Similarly, a balloon rises, without exception, whenever the combined weight of gas, envelope, etc.,

is less than that of the atmosphere displaced. Why then should not surface air, whenever it becomes specifically lighter than the air above it, also rise immediately? This undoubtedly is just what a limited volume of light air would do if actually surrounded on all sides by heavier air. But surface air is not completely surrounded by other air; its condition is somewhat analogous to that of a cork whose flat surface is pressed against the bottom of a vessel of water. The cork in this case does not rise, simply because it is pressed down by water above and not pushed up by water beneath. Similarly, warm air covering an extensive flat surface is pressed down by the superincumbent atmosphere and not pushed up by denser air below—there is no denser air below to push it up.

Obviously, though, even surface air under the given conditions is in an unstable condition. Hence it is important to determine that vertical temperature gradient which reduces superadjacent layers of air to the same density.

Auto-convection Gradient.—Suppose the atmosphere is perfectly quiet, what temperature gradient must any layer of it have in order that it may just initiate its own convection?

Clearly this gradient must be such that density shall just increase with elevation. That is, the ratio, $\frac{d\rho}{hd}$, must be just positive.

From

$$pV=\frac{p}{\rho}=RT$$

we get

$$\rho=\frac{p}{RT}.$$

Therefore,

$$d\rho=\frac{p}{RT}\left(\frac{dp}{p}-\frac{dT}{T}\right).$$

But

$$dp=-981\,\rho dh=-\frac{981\,dh}{V}=-\frac{981\,pdh}{RT}.$$

Therefore,

$$d\rho=-\frac{p}{RT}\left(\frac{981\,dh}{RT}+\frac{dT}{T}\right).$$

and

$$\frac{d\rho}{dh}=\frac{p}{RT^2}\left(\frac{981}{R}+\frac{dT}{dh}\right).$$

Hence, since $\frac{dT}{dh}$ is negative in the case under consideration,

$$\frac{d\rho}{dh}=0,$$

when

$$\frac{dT}{dh}=\frac{981}{R}.$$

But for dry air,

$$R=2.871\times10^{6}$$

and

$$\frac{dT}{dh}=-0.0003417.$$

Hence when $dT=-1^{\circ}$ C., $dh=29.27$ metres.

That is, in order that an under layer shall have the same density as the next above it the temperature must decrease 1° C. with each 29.27 metres increase of altitude, or 3.52 times faster than the adiabatic rate of 1° C. per 102.93 metres. In order that the lower layer shall be distinctly lighter than the upper, the temperature decrease with increase of altitude must be four or five times the adiabatic rate.

Obviously an extensive layer of warm, light air cannot all rise at the same time. It must rise locally and in streams, if at all. Similarly, the upper air must settle locally, if at all. But during the time mirage conditions are maintained the surface is strongly heated, so that any air that might reach it is not only warmed dynamically by the compression to which it is subjected, in settling down, but also by the heat acquired from contact with the surface. Hence, any settling of colder air from above amounts only to a partial removal of the hot and therefore light surface air.

It might seem, however, that the streams of rising air, above referred to, would ascend with great rapidity and in such volume as quickly to exhaust the supply of warm air. But, as already stated, the heat is being constantly supplied, and therefore the surface layer of hot air continuously renewed. Besides, the difference in weight between a given volume of a rising filament of warm air and an equal volume of adjacent air is at first only an exceedingly small fraction of the weight of either. Hence the acceleration with which it moves is correspondingly small. In nearly all cases the feeble streams of rising hot air presumably are pinched off by the adjacent denser air, and in this manner the breaks, as it were, in the integrity of the hot surface layer

mended and the entire convection divided into innumerable discontinuous filaments—mere fitful leaks from the constantly renewed reservoir of hot air.

It occasionally happens, however, that because of some disturbance an unusually large volume of warm air breaks through and rises in a columnar form. Such a column necessarily produces a chimney-like draft, since the air composing it is warmer and therefore lighter than the adjacent air on the outside. Hence, however established, such a column of warm air will maintain its integrity, or, rather, perpetuate itself, so long as the air that is forced into it from the base is warm and light. In this connection it apparently cannot be too strongly emphasized that the ascending air is not "drawn" up any more than air is "drawn" up a chimney. In each case the weight of the column of warm air is less than the weight of an adjacent equal column of cooler air, and the static unbalance is compensated kinetically; that is, air is forced up the column in question, as up a chimney, because of, and in proportion to, the difference between its density and that of the cooler descending air outside. Even a *vena contracta*, or restricted section, is formed in the column a short distance—one to five metres often—above the surface, as, and for the same reason that, such a restriction occurs in a jet of any fluid shortly after its issuance from an ordinary orifice.

The incoming air is almost certain to be directed to one side of the centre of the rising column, and, as the angular momentum thus established tends to remain constant, a correspondingly vigorous whirl is developed as the place of ascent is approached that gathers up such loose materials as dust, straws, leaves, etc. Furthermore, this rotation, whether clockwise or the reverse, perpetuates itself, though the details of how it does so are, perhaps, not fully understood. Pictet,[30] for instance, reports observing a dust whirl near Cairo, Egypt, that began on a small sand mound, remained stationary for nearly two hours, then, in response to a gentle breeze, wandered away, but maintained its sharply defined outlines and great altitude until lost in the distance, more than three hours later, or about five and a half hours after its inception.

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[30] Hildebrandsson et Teisserenc de Bort, "Les Bases de la Météorologie dynamique," vol. 2, pp. 286–288.

The diameters of these whirls (seldom more than a few metres near the ground) are too small for the direction of their gyration to be greatly influenced by the rotation of the earth. Hence nearly as many turn in one sense as in the other. They have even been reported to reverse, but it is probable that the apparent changes were only optical illusions similar to that which causes the cup anemometer to seem to reverse its rotation.

The height to which the whirling column rises (that is, the distance between the base of the column and its mushroom capital), the violence of the whirl, and, in some measure, even its duration, all depend upon the amount of surface heating and the extent to which the lower temperature gradient has been made greater than the adiabatic. When this heating is slight, only those small and gentle dust whirls with which all are familiar can be generated and sustained. When, however, the heating is pronounced, as it often is over level, desert regions, the whirl may assume almost tornadic violence. But, however violent, this sort of storm is never a tornado; it originates near the surface and is sustained by the supply of warm air from below, while the true tornado is generated and developed by conditions that obtain at the cloud level.

When dust whirls pass on to regions where the surface air is not so strongly heated—over bodies of water, for instance, or green vegetation—they no longer are fed with air relatively so light and, as a rule, quickly come to rest. Naturally, too, their frequency varies with topography, ground covering, latitude, season, and time of day. Thus they are most frequent of afternoons and least of early mornings, most likely to occur during summer and fall and least during winter and spring; most generally found in tropical and semitropical countries and least in regions of high latitude; more numerous over barren surfaces than over water and succulent vegetation; and, finally, more favored by level regions than by irregular and broken ground.

Cumulus Convection.

An interesting and important case of rapid vertical convection resulting from the local application of heat and consequent establishment of strong horizontal temperature contrasts is that displayed by the turbulence of the cumulus cloud. That strong vertical and irregular movements of the air often occur in large

cumulus clouds is known from the rapid boiling and rolling motions of their upper portions, from the descriptions of balloonists who have been caught up in the heart of a thunderstorm, and from the formation of hail within them. This latter phenomenon, the formation of hail, implies very definitely an uprush of at least 8 to 10 metres per second (20 miles per hour). This, in turn, on the theory of the chimney-like action of a warm central column of air, would demand, even neglecting viscosity, the equivalent of a column 1500 metres high and 1° C. warmer throughout than the surrounding atmosphere at the same level.

The chief cause of the horizontal temperature contrasts necessary to this rapid uprush obviously is the difference between the current temperature gradient of the surrounding atmosphere and the adiabatic gradient of the saturated air within the cloud itself, full details of which will be given in the chapter on the thunderstorm.

The common level, therefore, of a considerable number of detached but neighboring cumuli is one of rather vigorous convection—up within the clouds and down between them—however free from turmoil the atmosphere may be at other altitudes.

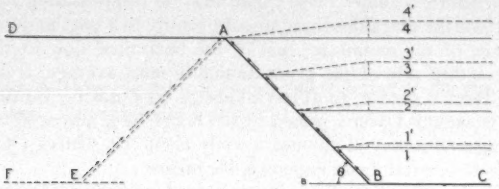
Valley Breeze.

During warm, clear days, when there is but little or no general wind, a gentle breeze, known as the valley breeze, commonly blows up the sides of mountains. The strength of this breeze varies greatly, owing to the size of the mountain, the material of its covering, and the conditions of its surroundings. The cause of some of these variations can be understood by reference to Fig. 28.

Case 1.—Mountain Slope Connecting Wide Plateaus of Different Level.—Let *AD* be the upper plateau, *BC* the lower, and *AB* the slope connecting them. Further, let the insolation be vertical, or the sun directly overhead. If now the slope *AB* is barren, or nearly so, it will become strongly heated and the adjacent air correspondingly expanded. As this lighter air is buoyed up by the adjacent denser atmosphere there results a draft in toward the side of the mountain. But this draft is all along the mountain slope from top to bottom, and thus in a measure the warm air is held in against the mountain side. Hence, the updraft along the side of the mountain is analogous to that in a chimney.

In addition to this obvious chimney effect of the mountain, there is, in the case under consideration, another source of upward winds that causes them to blow up along even shaded and cool ravines, unless snow-filled and very cold, in which circumstance local density is the controlling factor and air drainage, or a downward flow of the air, usually prevails, as will be more fully explained later. The early morning isobaric levels, 1, 2, 3, etc., are raised by heating during the day to higher levels, 1′, 2′, 3′, etc. From any point directly above the foot of the mountain the amount of this expansion obviously drops off, as indicated in the figure, as the side of the mountain is approached. Hence a pressure gradient is established toward the mountain side and

FIG. 28.



Effect of mountain on levels of isobars.

plateau beyond. If both plateaus are broad, a perceptible breeze of several hours' duration up the mountain slope and onto the higher plateau may be induced in this manner. Such winds grow stronger as the top of the mountain is approached. At night, after sufficient cooling has taken place, the winds reverse.

To form some idea of the possible magnitude of these effects, let the difference in level between *AD* and *BC* be 1.6 kilometres (one mile), and let the air between these levels be warmed on the average 5.5° C. (10° F.), then the increase of barometric pressure at *A* will be about 2.5 mm. (0.1 inch), with proportionate increases along the side of the mountain—quantities quite sufficient to produce a decided breeze.

Similar overflow winds occur also on the slopes of the isolated mountain, *BAE*, whenever the air on the opposite sides is unequally heated. Thus the landward side of a coast mountain, for instance, on a still warm day should have a breeze blowing up it and out to sea.

Case 2.—Isolated Mountain in the Midst of a Uniformly Heated Plain.—Here, too, the sides of the mountain are heated and corresponding upward currents induced. There also is expansion of the air over the adjacent plains and a tendency to establish pressure gradients towards the mountain, as in the case just discussed. But, however great this expansion, the gradients thus produced never cause, in the present case, more than a negligible wind. To make this statement obvious: Let the ridge *A* of the mountain be 1.6 kilometres (one mile) above the plains *EF* and *BC;* let the width of the base, *EB,* be 3.2 kilometres (two miles), and let the air be heated the same over one plain as over the other. Let the temperature increase of the air during the day be 5.5° C. (10° F.), or, suppose, 1 part in 50 of the absolute temperature. Under these conditions the compensating flow of air from the two sides must amount jointly to 1 part in 50 of the volume of the mountain; that is, the horizontal flow of the air from either side of the given mountain must average, from top to bottom, 1 part in 50 of 0.8 kilometre (0.5 mile). If, further, this is extended over a period of ten hours, as it may well be, the average velocity will amount to only about 1.5 metres (5 feet) per hour—certainly an imperceptible breeze.

Clearly, then, the breezes that ascend mountain sides on still clear days have two causes: (*a*) a chimney or draft effect due to surface heating—always present—and (*b*) a pressure gradient effect due to expansion of the air over an adjacent plain or valley—present only when this expansion is unequal on the opposite sides of the mountain, or when the base levels are decidedly unequal on the opposite sides.

Sea Breeze.

Whenever a strongly heated region adjoins one whose surface is less heated, a local circulation from the one to the other obtains, unless prevented by winds of a general circulation. Thus along the seashore, beside lakes and even at the edge of favorably situated forests, a breeze (sea breeze, lake breeze, and forest breeze, respectively) of greater or less strength sets in during dry summer forenoons, after the land surface has become sufficiently warmed to establish decided convection.

Since the sea breeze obviously ceases at that level where the

barometric pressure is the same above the land that it is above the water, and since the change of pressure with change of altitude is a function of temperature, it follows that its depth, never great, may easily be computed by replacing certain general terms of a suitable equation by observed temperature and pressure data. To develop such an equation:

Let ρ be the density of the air, then

$$-dp = \rho\, g\, dh,$$

in which $-dp$ is the small decrease in pressure corresponding to the small increase, dh, in height, and g the gravitational acceleration.

From the general equation,

$$pV = RT = \frac{p}{\rho},$$

in which p is the pressure, V the specific volume, R the gas constant, and T the absolute temperature, it follows that

$$\rho = \frac{p}{RT}.$$

Therefore,

$$-\frac{dp}{p} = \frac{g\, dh}{RT}.$$

Hence, integrating from p_0, corresponding to $h = 0$, to p, corresponding to $h = h$, if T is independent of h, which, as a first approximation, its average value may be assumed to be,

$$\log_e \frac{p}{p_0} = -\frac{gh}{RT}.$$

The value of the first half of this equation obviously remains the same when the corresponding, but more convenient, barometric readings b and B are substituted for p and p_0, respectively. Hence, also,

$$\log_e \frac{b}{B} = -\frac{gh}{RT}.$$

But the top of the sea breeze clearly is where there is no horizontal difference of pressure, or where $db = 0$, when h is constant. Hence, on differentiating this equation, keeping h constant, it is seen that

$$db = dB\left(\frac{b}{B}\right) + \frac{bgh}{RT^2}dT,$$

and that the depth of the breeze, h, is given by the equation,

$$h = -\frac{dB}{dT}\frac{RT^2}{gB}.$$

Consider a typical case: Let the sea-level reading of the barometer on land, less that at sea, or $dB = 0.5$ mm.; let the temperature over the land exceed that over the sea by $dT = 5°$ C.; let $T = 300°$ A.; let B, the sea-level barometer reading at sea, be 760 mm. R for dry air $= 2.871 \times 10^6$. Then the depth or thickness, h, of the sea breeze is given by the equation,

$$h = \frac{0.5}{5}\frac{2.871 \times 10^{10} \times 9}{981 \times 760} = 34{,}675 \text{ cm.} = 347 \text{ metres, approximately.}$$

The sea breeze, usually, as just explained, not more than 500 metres deep, starts on the water, seldom attains a greater velocity than 4.5 metres per second (10 miles per hour: the greater the temperature contrast the stronger the breeze), and extends inland, growing feebler and warmer, to a distance of only 16 to 40 kilometres (10 to 25 miles).

In a very important sense the circulation involved in this and all other local air convections is incomplete, since in such cases the path along which a given particle of the atmosphere flows is open and not closed. That is, the air that goes up over the heated land, in the case of the sea breeze, for instance, does not itself return by way of the water; it simply spreads out at the top of its ascent where its new temperature (above assumption of constancy of temperature not strictly correct), acquired by adiabatic expansion, is the same as that of the adjacent atmosphere, while the return branch, or down-flowing portion of the circulation, is broad and gentle. Hence the surface air always flows from the cooler toward the warmer mass. By day the sea or lake breeze is on shore, because the soil gets warmer than the evaporating water, and the similar forest breeze, always feeble, away from the woods.

WINDS DUE TO LOCAL COOLING.

Land Breeze.

By night, when the direction of the horizontal temperature gradient is the reverse of that during the day (that is, when the water surface is relatively warm and the soil cool, because of its rapid radiation), the direction of the surface wind is also reversed or offshore. This is the well-known land breeze.

Besides being reversed in direction and occurring at night instead of by day, the land breeze further differs from the sea breeze in usually being very much the weaker of the two, even though aided by the gravity flow of the cooler surface stratum of air. This is because *a*, the temperature contrast between land and water, is less by night than by day, and *b*, the surface friction over land which retards the land breeze, is greater than the water friction that affects the sea breeze. Hence, while the latter, as above stated, reaches 16 to 40 kilometres (10 to 25 miles) inland, the former seldom extends more than 8 to 10 kilometres (5 to 6 miles) to sea.

The depth of the land breeze, usually less than that of the sea breeze, obviously may be computed in precisely the same manner as the latter.

Mountain Breeze.

During clear nights, when there are only gentle winds or none at all on the tops of hills and mountains, there usually is a movement of the air down the sides and along the basin of every valley, most pronounced in ravines and along the steeper slopes. When the valley is long and steep and free from forests, especially if covered with snow, and when the flow is augmented by the influence of an adjacent cyclonic or anti-cyclonic system, the current of down-flowing air may attain the velocity of a gale and become, in fact, a veritable aerial torrent. The mountain breezes in such cases are a part of general wind systems, and in some localities have been given special names, such as the Bora, for example. The gentler winds of this class are known indifferently as the mountain breeze or mountain wind. In discussing a general class of descending winds to which he gives the name *Katabatic* winds, Shaw [31] gives the following elegant description of the mountain breeze:

[31] Sir Napier Shaw, "A Barometer Manual for the Use of Seamen," 8th ed., 1916, p. 23.

"At night there is a natural tendency, easily explained, for the air to get calm at the surface because it gets cold. On clear nights the whole landscape gets cooled by radiation, and the air is cooled still further. As it cools it runs down the hill like water until the whole valley becomes filled with a river of air flowing down towards the sea.

. . . . . .

"It may be allowed that the air gains in temperature by 1° for every 190 feet of drop, and that the rise of temperature will diminish the density of the falling air. That will diminish and may stop the flow, but if the air is sufficiently chilled to start with and gets further chilled by a cold surface on the way, very violent winds may be produced. It may be of interest to suggest that the speed attained depends upon how long the flow is kept up. When it first begins, the falling front has to push the air beneath it out of the way, but when the current is established from top to bottom, there is only the surface friction to retard it, and the terminal velocity will approach to that given by the ordinary formula $v = \sqrt{2\,gh}$; if the velocity is to be given in feet per second, v becomes equal to $8\sqrt{h}$."

Glacier Winds.

It is well known that a draft of cold air often is found blowing out from a cave-like opening in the lower end of a glacier, hence called glacier wind. Similar winds, blowing out during summer and in during winter, occasionally are found at the mouths of caves, called blowing caverns, on the sides of hills or mountains. In the volcanic mountains of Japan such places are numerous and extensively used for cold storage.[32] In each case the explanation of the phenomenon is the same and obvious. The cavity extends quite through the glacier, or earth, as the case may be, from its lower to its higher openings. Let this difference in elevation be 250 metres; let the average temperature of the air inside the cavity be 0° C., and of that outside at the same level 15° C. The density of the inner air will be to that of the outer approximately as 19 to 18, and the pressure head, producing an inverse chimney effect, about 14 metres. Neglecting friction—usually, however,

[32] S. Suzuki and T. Sone, Tohoku Univ. Sci. Reports, 3, pp. 101–111.

an extremely important factor—this would give the exit air a computed velocity of about 16.6 metres per second (37.1 miles per hour)—a very appreciable gale. The velocity or strength of this wind, other things being equal, varies as the square root of the difference in level between the lower and upper openings.

In the case of a glacier, drainage obviously obtains in substantially the same manner, whether the air passes in a concentrated stream through a cavity or along a crevice within the ice, or merely flows in a broad sheet over the top surface. Clearly, too, the same sort of aerial cascades (exaggerated mountain winds) must occur, especially during summer nights, over any banks of snow that may exist in the upper and steeper reaches of canyons and mountain valleys. Such winds necessarily are shallow and therefore, when swift, a treacherous source of danger to the landing aviator.

The Bora.

From the above explanation and examples of aerial drainage it is obvious that similar winds must often blow down steep slopes that separate high, snow-covered plateaus or mountain ranges from adjacent bodies of relatively warm water. Thus when an anticyclone covers such a region during winter the surface air becomes very cold and correspondingly dense until, unless otherwise dissipated, it overflows restraining ridges or drains away through passes and gaps. Clearly, too, this flow must be most frequent and strongest during the early morning, since that is the coldest time of the day, and least frequent of mid-afternoons. In many instances during anticyclonic weather the air as it leaves the snow fields is so cold that in spite of dynamical heating it even reaches the sea at freezing temperatures and very dry. When, however, the drainage is amplified, if not even started, by the pressure gradients (to which the final velocity bears no special relation) due to a properly situated "low," it usually is associated with a counter cyclonic current above and therefore accompanied by rain, sleet, or snow.

Probably the best known of all these violent fallwinds is the *bora* of the northeast Adriatic, especially at Trieste, Fiume, and Zengg. The boras of these places, however, are not from the north, as the name implies, but rather from the northeast and east-northeast.

Another excellent example of this kind of wind occurs at Novorossisk, a Russian port on the northeast coast of the Black Sea, where it blows down from a nearby pass in the mountains, occasionally with destructive violence. Probably, also, the brief but sudden and violent williwaws of steep, high latitude coasts have a similar origin.

Mistral.

Another instance of convection due essentially to cooling is the well-known mistral, or dry, cold northerly wind of the Rhône Valley. Here the more or less persistent winter low over the warm waters of the Gulf of Lyon to the south and the frequent highs over the snow-covered plateaus of southeastern France to the north often coöperate in such manner as to produce extensive air drainage down the lower Rhône Valley. In general the cause of the mistral and its actions are the same as those of the bora. It is less violent, however—its path less steep, and therefore itself not so distinctly an aerial cataract. Similar winds occur, of course, under like circumstances in other parts of the world. but the mistral is the best known of its class.

Norwegian Fallwinds.

An extensive fallwind, which, because of its importance and the fact that it is more or less unique, deserves especial mention, frequently occurs during winter along the coast of Norway. Sandström,[32] in one of his interesting atmospheric studies, describes it as follows: "In winter, as one steams along the northwest coast of Norway, there is frequent opportunity to observe a peculiar meteorological phenomenon. Fine weather prevails over a narrow strip along the coast, while a heavy bank of cloud is visible out to seaward. Of course, coastwise traffic is greatly favored by this fine-weather strip and takes full advantage of it. Throughout this zone of fine weather prevails a cuttingly cold wind so strong that one can scarce stand against it when on deck. The maximum velocity of this wind is attained near shore, where the water is whipped up into whirls and miniature waterspouts. Evidently the wind here plunges down upon the water from above, and with great force.

[32] Mount Weather Bulletin, 5, p. 129, 1912.

"Upon leaving the steamer and travelling inland up the mountain slopes on skis, strong head winds oppose progress. This easterly wind is still very strong on the great divide of the Scandinavian Peninsula. But observations of the cloud caps on the highest peaks of the range show that a westerly wind is blowing at those great altitudes. It is clear that a lively interchange of air between the North Atlantic Ocean and the continent is taking place above the Scandinavian highlands. This exchange takes place along either side of a glide surface whose altitude above the ground at the divide may be estimated at about 1000 metres. In fact, at the kite station Vassijaur it proved almost impossible to raise the kites above that level, evidently because they there encountered a glide surface through which they cannot pass, since the wind has opposite directions on the two sides of this surface, and therefore calm must prevail at the glide surface itself. The altitude of this glide surface decreases to the Atlantic Ocean. The air below this surface flows toward the west, and above the surface it flows toward the east."

Continental Fallwinds.

From the above discussion of winds that result from surface cooling it is obvious that they are of very general occurrence, especially during cold weather and down the valleys and slopes of high, snow-covered regions. Hence one would expect drainage winds to obtain to a greater or less extent during winter over the middle and high latitude regions of every continent. Where the elevation and slope are slight, however, as they are, with but minor exceptions, over all North America east of the Rocky Mountains, over Russia, and over Siberia, except the eastern portion, this drainage necessarily must be comparatively sluggish.

On the other hand, there are two regions of continental extent—Greenland, with an area of about 827,000 square miles, and Antarctica, with an area of, roughly, 4,600,000 square miles—that are ideally located for, and perfectly adapted to, the production of strong and almost continuous fallwinds.

Greenland, as is well known, is continuously covered with an enormous ice cap that rises to a gently rounded plateau of, roughly, from 2000 to 3000 metres (7000 to 10,000 feet) elevation. This plateau, whose crest runs approximately north and south, has been crossed several times—six in all—at as many

different places, and in each case nearly constant down-slope or drainage winds of greater or less strength were experienced.

Throughout its great area, therefore, Greenland is a region of almost perpetual aerial cascades and cataracts. The continuous refrigerative influence of its enormous ice cap, covering an area 18 times that of the state of Pennsylvania and rising at places to an elevation of over three kilometres (two miles), not only controls the direction and velocity of nearly all local winds, but obviously must be of decided influence on the general circulation of the middle and higher latitudes of the whole northern hemisphere—an important circumstance that will be taken up later.

Antarctica, according to the reports of all its explorers, is quite as completely covered with ice as is Greenland, and it also rises, more or less dome-like, to fully as great altitudes. Hence it would seem that its general effect on the movement of the air must be very similar to that of its great counterpart in the northern hemisphere—an inference now fully borne out by the many accounts and records of those who have skirted its coasts, crossed its plateaus, or wintered on its borders. Sir Douglas Mawson, for instance, who spent many months during 1912–13 at Adelie Land, latitude 67° S., on the edge of the continent almost directly south of Tasmania, reports an average wind velocity for an entire year, from the interior toward the sea, of more than 22.4 metres per second (50 miles per hour). "Day after day," he says, "the wind fluctuated between a gale and a hurricane." Velocities of 100 miles and over per hour occurred, and gusts of even much greater velocity occasionally were recorded. These measurements were made at the main station on the declivitous border that connects the inner ice plateau with the ocean. Back some distance inland, where the slope is gentle, the winds were less severe. At sea, also, these continental drainage winds decreased in intensity with increase of distance from shore, and ceased altogether at a distance of about 300 kilometres (187 miles), where the westerlies became effective. Obviously, therefore, this particular station was located in one of the windiest places in the world—in an aerial cataract where the cold drainage air of the ice plateau rushes down a steep coastal slope to the sea.

Similar winds of varying intensity and irregular duration are reported all along the Antarctic border, from every inland station

and from end to end of every exploring trail. Clearly, then, the winds of Antarctica, though due essentially to cooling, nevertheless, because of the extensive area they cover, belong also to those great circulations that are strongly influenced by earth rotation, and therefore constitute an important part of the general circulation of the atmosphere, under which head they will again be considered.

(To be continued.)

Gear Ratios for Cars in City Service. ANON. *(Electric Railway Journal,* vol. 50, No. 4, p. 132, July 28, 1917.)—The only effect of a low gear ratio, or the use of large pinions in city service, is to provide high maximum speed, which has no value, and provides this high speed at the expense of energy consumption and schedule speed, which have great value. The capacity for high maximum speed does not necessarily produce high schedule speed; in other words, a city car's ability to run fast is usually worthless as a time saver.

That the very definite laws governing gear ratios for city service should be disregarded to the extent that companies retain the numerous 16-tooth and 17-tooth pinions that are in operation to-day under congested traffic conditions may perhaps be due to the complication arising from the common custom of considering both distance and time elements in connection with the subject of city car movement. However, consideration of only the time element is quite feasible. Thus it may be said that the reason why high maximum speed is worthless in city service is that the stops come at intervals of only about 40 seconds, or some other figure of that order. If a 6-second stop is assumed, the next time interval devoted to the movement of the car between stops becomes 34 seconds, and even with straight-line acceleration and braking at a rate of 1.5 m. p. h. p. s., the maximum speed that the car could attain would be 25.5 m. p. h. That is, with 34 seconds devoted to car movement, only 17 seconds could be allowed for acceleration, the remainder having to be reserved for braking in order to make the next stop. Even if the car were geared to make 30 m. p. h. and had motors large enough to accelerate at 1.5 m. p. h. p. s., with that gearing it would be impossible to attain the 30-mile speed.

If a pinion small enough to reduce the maximum speed from 30 m. p. h. to 22.5 m. p. h. should be installed, the rate of acceleration would obviously be increased to 2 m. p. h. p. s. With the same brak-

ing rate of 1.5 m. p. h. p. s. as before, and the same number of stops, the whole advantage gained by the smaller pinion may be applied to saving energy. In this case power may be shut off after 9.75 seconds of acceleration, allowing the car to coast for 12.25 seconds, and then applying the brakes for 12 seconds the run may be completed in the same time interval as before. The saving of energy will be 43 per cent., because of the greatly reduced time during which power is applied. In cases where stops are reasonably frequent, city cars now fitted with pinions of 16 or more teeth may with advantage be fitted with smaller pinions. The change, for example, even from a 16-tooth pinion involves about 6 per cent. less time on resistance, and that alone in the course of a year effects a saving of about $20 per car. The capital expense is, of course, nothing, provided the change is made at the time when worn-out gears are being replaced.

Modified Pitot Gives High Accuracy. ANON. (*Engineering News-Record*, vol. 78, No. 11, p. 570, June 14, 1917.)—The pitot tube has long been used as a device for measuring the flow of liquids and gases, but only when used with the utmost care have the results proved uniform. Fundamentally the pitot tube consists of a U-tube one leg of which enters the stream normally to the direction of the flow, while the other leg is bent around so that the cross-section of the tube faces the direction of flow. The difference in height to which the liquid rises in the legs of the U-tube represents the velocity head of the stream. The velocity computed from this head entails a variable coefficient whose value is subject to some uncertainty.

With a view to eliminating this defect, Prof. H. A. Thomas has devised what may be termed the "Hydraulic Shunt-Flow Tube," which is described in the March issue of the *Rose Technic*, page 176. In this device, as before, one leg of the U-tube enters the stream normally to the direction of flow, but the other leg communicates with a tube placed within the stream parallel to the direction of flow, through which discharge takes place. If this discharge be so governed that the pressure heads in both branches of the U are alike, the conditions of flow in the main stream and discharge tube are identical and the velocity of the stream may be deduced from the quantity discharged, the area of the tip opening, and the tip coefficient. It is possible to demonstrate that turbulent flow should not affect the coefficient of this tip. Theoretically the tip-coefficient should be unity, but a series of experiments undertaken with this in view show that it varies less than 4 per cent., while the pitot coefficient under like conditions varies more than 4 per cent.

MODERN DYNAMO ELECTRIC MACHINERY.*

BY

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ROTARY CONVERTERS.

One of the most interesting developments in the last few years is that of the sixty-cycle rotary converter.[25] Up until 1909 the record of these machines was so poor that many operating engineers preferred the motor-generator set in spite of the fact that it cost more, had a lower efficiency, and occupied more space. Many improvements, however, have been made in the last eight years, both in design and in construction, with the result that for voltages less than 750 the sixty-cycle rotary is being installed in large numbers. The Aluminum Company of America has installed eighteen of these machines, each with a normal capacity of 2500 kilowatts, in its new plant at Messina.[26]

Theory of Operation.—In order the better to understand the problems involved in the design of modern rotary converters it will be advisable to review the theory of operation of the polyphase machine.

The diagram in Fig. 82 represents a two-pole direct-current generator with the armature winding tapped at six points to form a six-phase converter, which converter is connected to a three-phase line through transformers, the diametrical connection being used. If three-phase alternating voltages are applied to the primary side of the transformers, the converter will run as a synchronous motor, but at the same time a direct voltage will be found between the brushes $B+$ and $B-$ just as if the machine were the direct-current generator of a motor-generator set. If the brushes are connected to an external circuit and a direct current is drawn from the machine, equivalent alternating currents will be drawn from the alternating-current mains just as if the machine were the synchronous motor of a motor-generator set. The resultant current in an armature conductor at any instant is the

* Concluded from page 433, September issue.

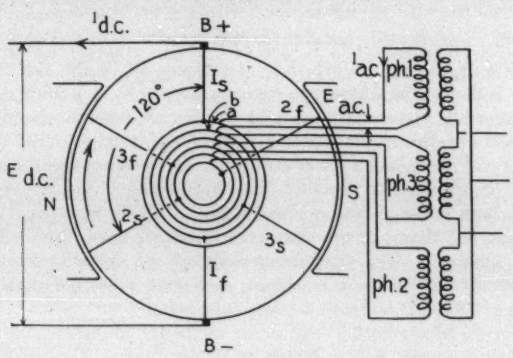
[25] "The Engineering Evolution of Electrical Apparatus," by Newbury, *Electric Journal*, vol. 12, p. 27.

[26] "45,000-kw. Synchronous Converter Substation," by Burnham and Muir, *General Electric Review*, vol. 18, p. 873.

difference between the motor and the generator currents that are flowing in the conductor at that instant.

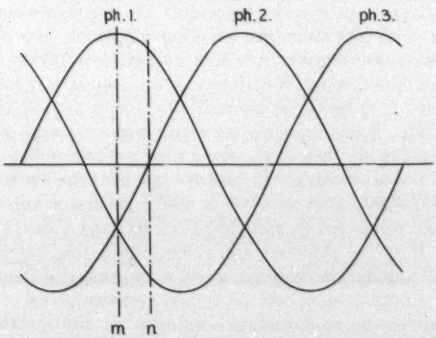
Voltage and Current Relations.—There is a fixed ratio be-

FIG. 82.



Six-phase rotary converter connected to a three-phase line by the diametrical connection of transformers.

FIG. 83.



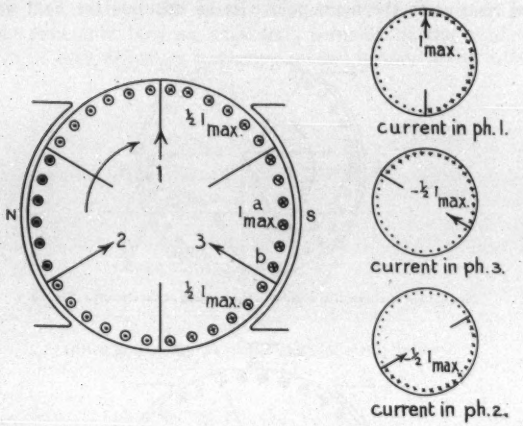
Currents in the three-phase leads of a six-phase rotary converter.

tween E_{ac}, the back-generated alternating voltage, and E_{dc}, the generated direct voltage, because both are caused by rotation in the same magnetic field. In Fig. 82 the back-generated voltage between the slip rings *a* and *b* has its maximum value when the armature is in the position shown, but the voltage between these

two rings at that instant is also equal to E_{dc}, the voltage between the brushes, so that

$$E_{dc} = \text{maximum value of } E_{ac}$$
$$= \text{effecive value of } E_{ac} \times \sqrt{2}$$

FIG. 84.



Distribution of alternating current in the winding at the instant *m*, Fig. 83, the winding being connected six-phase, as in Fig. 82.

For this particular type of rotary converter we also have the relation

$$E_{dc}I_{dc} = 3 \times E_{ac} \times I_{ac} \times \text{effic.} \times \text{power factor}$$

or

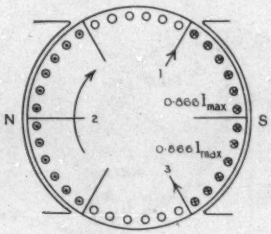
$$I_{ac} \text{ effective} = 0.47 \times I_{dc} \times \text{effic.} \times \text{power factor}$$

Armature Reaction.—Consider the case where the field excitation is so adjusted that the rotary is operating on the alternating-current side as a synchronous motor at 100 per cent. power factor. Under these conditions the current in each phase of the winding reaches a maximum at the same instant as the back-generated voltage in that phase, but is directly opposed to it. At the instant the voltage in phase 1 has its maximum value the armature is in the position shown in Fig. 84, the currents in the three phases have the values shown at *m* in Fig. 83, the distribution of current in each phase of the winding is as shown in the three diagrams in Fig. 84, and the resultant distribution of cur-

rent in the winding due to all three phases is also shown. The armature reaction is cross-magnetizing as in a direct-current machine.

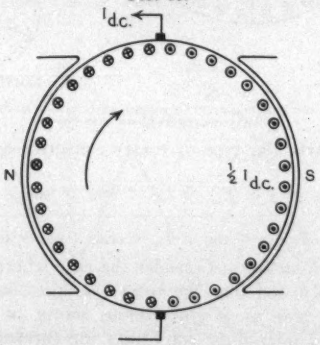
It is generally assumed that the armature field of a polyphase synchronous motor is constant in magnitude and is fixed in direction relative to the main poles; let us examine the field at the

FIG. 85.



Distribution of alternating current in the winding at the instant *n*, Fig. 83.

FIG. 86.



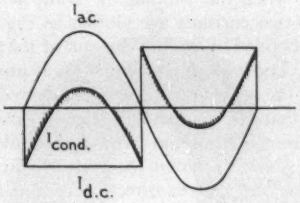
Distribution of direct current in the winding at any instant.

instant *n*, Fig. 83, when the current in phase 2 is zero. The armature is then in the position shown in Fig. 85, and the resultant distribution of current in the winding due to all three phases gives a magnetomotive force in the same direction as in Fig. 84.

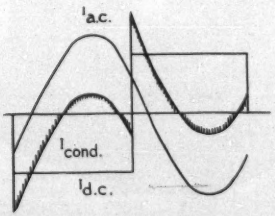
If the machine were acting as a direct-current generator, the

direction of the currents in the conductors would be as shown in Fig. 86, and if this latter diagram be superimposed on either Fig. 84 or 85 it will be seen that, so far as commutation is concerned, the rotary converter is like a partially compensated direct-current generator; also, that the average copper loss per conductor is less than that of the same machine operating as a direct-current generator, because, as already pointed out, the resultant current in each armature conductor at any instant is the differ-

FIG. 87.



Variation of current in the conductor *a* during one revolution.



Variation of current in the conductor *b* during one revolution.

ence between the direct and the alternating currents that are flowing in the conductor at that instant.

The armature reaction due to the direct current is shown in Fig. 86 and has a value per pair of poles of

$$\tfrac{1}{2}\ Z \times \tfrac{1}{2}\ I_{dc} = 0.25\ Z\ I_{dc} \text{ ampère-turns}$$

Where Z is the total number of armature conductors.

The armature reaction due to the alternating current has a value per pair of poles of

$$\tfrac{1}{3}\ Z \times I_{max} = 0.22\ Z\ I_{dc} \text{ from Fig. 84}$$

$$\tfrac{1}{3}\ Z \times 0.866\ I_{max} = 0.19\ Z\ I_{dc} \text{ from Fig. 85}$$

so that the resultant armature reaction varies during $^1/_{12}$ of a cycle between 0.03 $Z\ I_{dc}$ and 0.06 $Z\ I_{dc}$ ampère-turns per pair of poles, or between 12 and 24 per cent. of the armature reaction due to the direct current acting alone.

Armature Heating.—The variation of the current in the armature conductors during one revolution may be found as follows: The direct current in conductors *a* and *b*, Fig. 84, reverses as these conductors pass under the brush, while the alternating current in these conductors is the same at any instant and has its maximum value when the winding is in the position shown in Fig. 84. These two currents are plotted in Fig. 87 and the resultant current obtained by finding the sum of the two components at each instant. The loss in the conductors is proportional to the average value of the square of the resultant current, and is greater in conductor *b* than in conductor *a*, but in both conductors is less than would be caused by the direct current alone. The effect of reducing the power factor of the converter is to increase the alternating current for a given direct current and also to change their phase relation so that they do not neutralize so closely. The relative loss in the conductors for different power factors and for different polyphase connections is given in the table below.

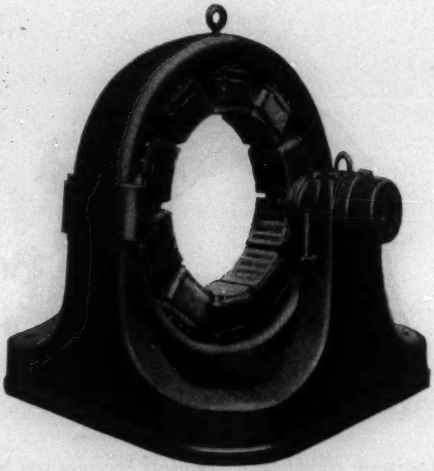
Number of collector rings	Relative armature copper loss			Relative loss in conductors next the taps		
	Power factor, 100 per cent.	Power factor, 98.5 per cent.	Power factor, 94 per cent.	Power factor, 100 per cent.	Power factor, 98.5 per cent.	Power factor, 94 per cent.
Direct Current	1.0	1.0	1.0	1.0	1.0	1.0
3	0.587	0.627	0.753	1.249	1.594	2.048
6	0.274	0.304	0.400	0.430	0.614	0.874
12	0.209	0.236	0.326	0.249	0.354	0.525

The above table shows why rotary converters are operated at about 100 per cent. power factor and are not used, as are synchronous motors, for power factor control of circuits. It also shows the advantage of a large number of phases; few rotaries above 250-kilowatt output have less than six phases, while twelve phases have been considered for larger machines.

Troubles in Rotary Converters.—The rotary converter is subject to the troubles of both the synchronous motor and the direct-current generator. One of the first troubles encountered was

hunting. This was cured by the addition of dampers to the pole face. One of the first type to be used was the cast grid damper shown in Fig. 88, and this has gradually been improved upon until now the usual practice is to put a squirrel-cage winding on the pole faces, as shown in Fig. 89, which winding, as in the case of the squirrel-cage induction motor, causes a restoring torque to be developed as soon as the armature speed varies from synchronism, which it does when the machine is hunting.

FIG. 88.



Rotary converter field, showing copper dampers on poles.

The problem of hunting having been solved, that of commutation now received additional attention, and as the rotary converter designs were worked up by men familiar with direct-current practice, it is not surprising to find that the development of the direct-current generator was paralleled by the development of the rotary converter, and that interpoles began to come into general use in 1909 and the speeds for a given output to increase.

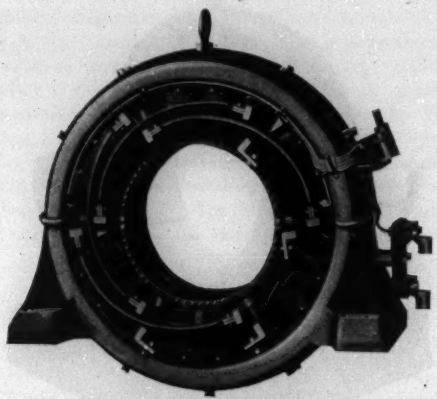
In the case of the motor-generator set, where there is no restriction to the speed except that the operation shall be satis-

factory and the cost a minimum, the gradual increase in speed is indicated by the following figures:

Date	Poles	Kilowatts	Revolutions per minute
1906	10	1000	514
1910	8	1000	750
1916	6	1000	900

The maximum speed for a direct-current machine of a given output is limited by sparking, and the sparking limit may be raised by the addition of interpoles. The speed is also limited by the tendency of the machine to flash over when the average voltage

FIG 89



Rotary converter field, showing squirrel cage.

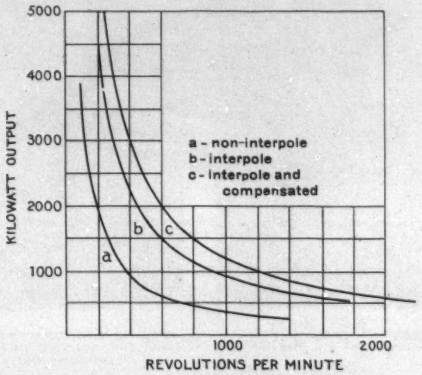
between adjacent commutator segments becomes too high, and the flash-over limit may be raised by the addition of a compensating winding. Certain assumptions being made, Fig. 90, which is a reproduction of Fig. 26, shows the highest safe speed at which a given output may be obtained.

The non-interpole rotary converter has the advantage over the corresponding direct-current generator that the armature reaction is very small, so that the commutating field under the pole tip is not weakened with increase of load; one would therefore expect that the speeds of the non-interpole converters of 1909 would not be lower than those given by curve *a*, Fig. 90, and

that interpole converters could be built for the speeds given by curve *b*. That this is indeed the case may be seen from the following table:

Kilowatts	Revolutions per minute in 1909	Revolutions per minute in 1917
500	500 at 25 cycles	
	600 at 60 cycles	
1000	375 at 25 cycles	900
	360 at 60 cycles	
1500	250	600
2000	187	
2500		400
4000		214
5800		225

FIG. 90.



Maximum output of direct-current generators.

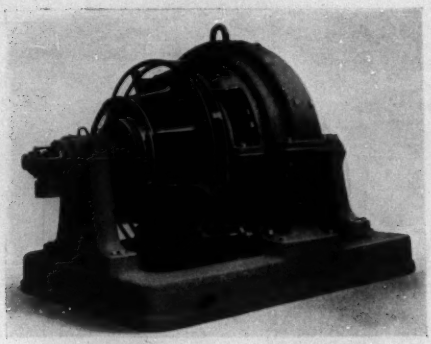
The addition of interpoles has therefore caused a large increase in the speed and a corresponding decrease in the dimensions and in the cost of rotary converters.[27]

It must be noted, however, that, for a given frequency, the number of poles must decrease as the speed is increased, so that there are not so many sets of brushes at which to collect the current; therefore, as shown in Fig. 91, the commutators tend to become large relative to the rest of the machine.

[27] "High-speed Rotary Converters," by McK. Yardley, *Electric Journal* vol. 11, p. 562.

It is largely because of this fixed relation between frequency, speed, and number of poles that sixty-cycle converters are more difficult to design and build than are those for twenty-five cycles;[28] there are so many sets of brushes that, as shown in Fig. 92, they are crowded together and the machine is liable to flash over. The

FIG. 91.



1000-kilowatt, 600-volt, 60-cycle, commutating-pole rotary converter. Modern type.

distance between adjacent sets of brushes can be increased only by an increase in the peripheral velocity of the commutator, thus:

$$\text{frequency} = \frac{\text{poles}}{2} \times \frac{\text{R.p.m}}{60}$$

$$= \frac{\pi D \times \text{R.p.m.}}{12} \quad \frac{\text{poles}}{\pi D} \quad \frac{1}{10}$$

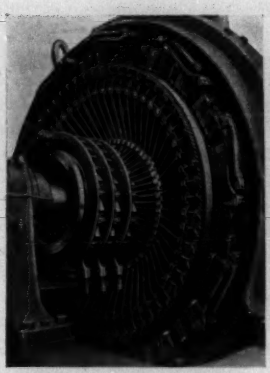
$$= 0.1 \left(\frac{\text{commutator velocity in feet per minute}}{\text{distance between brushes in inches}} \right)$$

Up until 1909 it was not considered good practice to build commutators to operate with a peripheral velocity in excess of 4000 feet per minute, so that the distance between adjacent brushes of a sixty-cycle converter was limited to about 6.7 inches, the neutral zone was narrow, and, as shown in Fig. 92, there were many sets of brushes to be adjusted. If the minimum width of

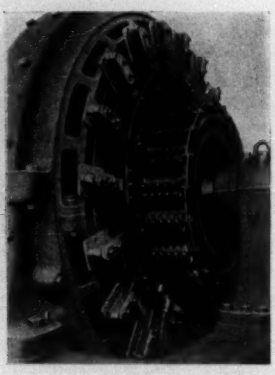
[28] "Sixty-cycle Rotary Converters," by Lamme, *Electric Journal*, vol. 13, p. 1124.

segment and mica of such a commutator is limited to $^3/_{16}$ inch, then the number of segments per pole cannot exceed 36, nor can the average voltage between adjacent commutator segments be less than 16.7 for a 600-volt machine. This value is rather close to the flash-over limit, particularly if the resultant armature reaction is such that the main field is distorted, as is the case when the machine is operating at power factors other than 100 per cent., and also when it is hunting. Improvements in the design of high-speed commutators, as for example the use of the three

FIG. 92.



Alternating-current side of rotary converter, 1000 kilowatt, 600 volts, direct current, 60 cycles, six-phase.



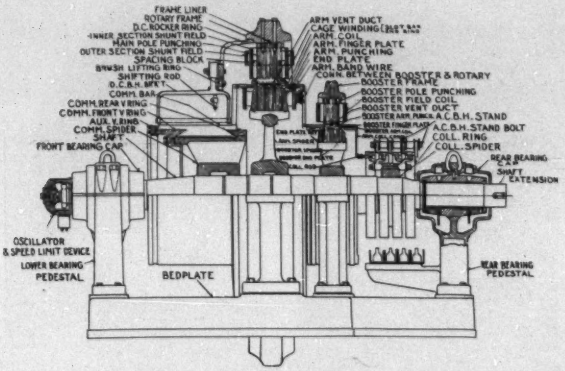
Direct-current side of rotary converter, 1000 kilowatt, 600 volts, direct current, 60 cycles.

V-rings shown in Fig. 93, also improvements in the methods of constructing and seasoning of commutators, have made it possible to increase the peripheral velocity to 5400 feet per minute and to increase the distance between adjacent sets of brushes to 9 inches, so that it is now possible to use 48 segments per pole. There is the further advantage that the width of the neutral zone is increased 20 per cent., and the machine, therefore, is not so sensitive to slight inaccuracy in the setting of the brushes.

Interpole Design.—In a direct-current machine, the interpole excitation must be large enough to overcome the armature reaction and also to produce the desired commutating field, it there-

fore has a value of about 1.25 times the armature ampère-turns per pole; if, however, the machine carries a compensating winding on the pole face to neutralize the armature reaction, the interpole excitation will have a value of only about 0.25 times the armature ampère-turns per pole. In the case of the rotary converter the armature reaction is not zero; it is pulsating and has an average value of about 15 per cent. of the direct-current armature reaction, so that, in order to produce the desired commutating field, an interpole excitation of about 0.4 times the armature ampère-turns per pole is required.

FIG. 93.



Cross-section of a synchronous booster rotary converter.

It has already been pointed out in the section on direct-current machines that, due to interpole saturation, the commutating field is not directly proportional to the load current, and that the overload capacity of the machine is thereby limited. In the case of machines such as rolling-mill motors, which are subject to large overloads, it is necessary to prevent saturation of the interpole core, and this, we saw, was accomplished by the use of the pole-face compensating winding. So far as overload capacity is concerned, the rotary converter does not differ greatly from the compensated direct-current machine.

In at least two respects the problem of commutation is more difficult in the case of the rotary converter than in the case of

the direct-current machine. In the first place, the armature reaction is pulsating and tends to cause pulsation of the interpole field. Commutation is also impaired by the hunting of the machine, because then there is a pulsation of energy superimposed on the normal condition of operation. The machine is running alternately above and below synchronous speed; while it is accelerating, kinetic energy is being stored in the revolving system, and while decelerating, this energy is given back to the line. The alternating-current armature reaction due to this effect is, first, that of a motor and then that of a generator, and so adds an alternating component to the interpole field.

Both of these pulsating fields can be eliminated if a short-circuited turn is placed around the interpole, and this result is accomplished by the use of a complete squirrel cage for a damper. The squirrel cage, in addition, is more effective in preventing hunting than is the grid on the pole face. The use of such a short-circuited turn around the interpole has been avoided in direct-current machines because it prevented the interpole flux from responding instantly to large and sudden changes in load, but experience has shown that, in the case of the rotary converter, it is of greater importance to minimize hunting and to dampen out the oscillations of the interpole flux.

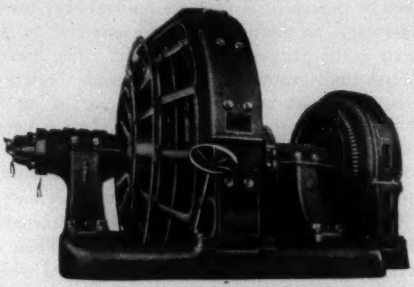
Brush Lifting.—Most rotary converters are started as induction motors from the alternating-current side. When voltage is applied to the armature a gliding field is produced which moves at synchronous speed relative to the armature surface. This field causes a large current to flow in the turns that are short-circuited by the brushes, and the interruption of this current when the armature begins to rotate causes destructive sparking. This sparking has become serious now that interpoles have been added, since they greatly reduce the reluctance of the path of that part of the flux by which the short-circuited coils are cut; it has therefore been found necessary to raise the brushes from the commutator when interpole rotary converters are started from the alternating-current side.

Protection Against Short-Circuits.—When the direct-current side of a rotary converter is short-circuited, there is a large rush of current which causes bad sparking and invariably causes the machine to flash over. Various baffles of moulded asbestos have been devised to smother the arc and prevent it from burning the

armature winding and the brush rigging, but a more promising scheme is to open the circuit before the current has time to grow to a value large enough to start the trouble. A circuit breaker has been devised which will introduce a resistance into the leads within 0.005 second after the short-circuit has taken place and will then disconnect the machine from the line.

Voltage Control.—The rotary converter is essentially a constant ratio machine, but it is often desired to control the voltage of the direct-current side, the alternating applied voltage being constant. Three methods have been used for this purpose. The first to come into general use was the addition of a polyphase induction regulator to the alternating-current side of the con-

FIG. 94.



2000-kilowatt, 180 r. p. m., 700-volt, synchronous converter with revolving field alternating-current booster.

verter, by means of which the voltage at the converter terminals could be varied above or below that of the line. This method is still used for the control of small machines. Two other methods were put on the market about 1908; namely, the split-pole converter [29] and the booster converter, but, because of certain difficulties in the addition of interpoles to the former machine, it has gradually given way to the latter. The booster converter consists of an alternating-current generator and a rotary converter with the same number of poles, both mounted on the same shaft. The generator may be of the rotating armature type as shown in Fig. 93, or, if this would require the use of too long and flexible

[29] "Modern Types of Synchronous Converters," by Burnham, *General Electric Review*, vol. 15, p. 74.

a shaft, the rotating field type shown in Fig. 94 may be used. The voltage variation generally required is 15 per cent. above and below the average voltage for which the converter was designed, and this is accomplished by the use of a generator which has a capacity of only 15 per cent. of that of the converter itself. Since this output is comparatively small, there is no reason why the boosting generator should not be run at a much higher speed than that of the converter, except that in such a case the booster would have to form part of a synchronous motor generator set; this construction, however, has been used.

With the addition of the booster a new problem of interpole design was introduced. When the booster field is excited so that the booster voltage is added to that of the line, the booster acts as a generator and must therefore be driven mechanically by the converter acting as a synchronous motor, so that the alternating current in the converter is greater than that which corresponds to the direct-current output; there is therefore a motor armature reaction in addition to the normal reaction that exists due to the converter action of the machine, and this additional reaction is approximately proportional to the per cent. by which the voltage is boosted. When, on the other hand, the booster field is reversed so that the booster voltage opposes that of the line, the booster acts as a motor and delivers mechanical power to the converter shaft; the alternating current in the converter armature is then less than that which corresponds to the direct-current output; there is therefore a generator armature reaction in addition to the normal reaction due to the converter action of the machine. The interpole excitation must therefore consist of two parts—that which it would have if the booster were removed, and an additional excitation which is proportional to the booster voltage.[30]

Much more might have been written on the subject of modern rotary converters, alternators, and direct-current machines, and many other types might have been discussed, but this would have carried us beyond the scope of a series of articles that were written primarily for those central station engineers who are interested in what has already been done to obtain the maximum output from a given weight of material, and in what the prospects are for still further reductions.

[30] "Synchronous Booster Rotary Converters," by McK. Yardley, *Electric Journal*, vol. 11, p. 267.

Catalysis. D. W. HORN. (*Transactions of the Wagner Free Institute of Philadelphia*, vol. viii, p. 97, July, 1917.)—Contact underlies chemistry. Bodies may influence each other at almost incredible distances, but this action is physical, not chemical. Briefly, no contact, no chemical action. In the time-honored generalizations of chemistry, its "fundamental laws," the action of pure substances upon each other was considered without reference to the effects of adjacent bodies. In some few instances, however, the effects of adjacent bodies were so striking as to compel early attention. Until recent years the multiplication of such instances has been slow. Such action or influence of an adjacent body may be covered by the term "catalysis," introduced by Berzelius, the famous Swedish chemist, in 1834.

In 1836 Berzelius compiled all cases known in which, by the presence of a foreign body, a chemical reaction is hastened without the foreign body itself being changed. These foreign bodies thus acting he called "catalysts." Historically, catalysis is not a new phenomenon. Processes of fermentation were known to the ancients, and these involve catalysts. In fermentation by yeast, the yeast plant produces the catalyst, or enzyme, as it is more frequently called. In sharp contrast with chemical reactions that, when not catalyzed, proceed at so slow a rate as to produce less than noticeable amounts of products stand the reactions that are so rapid as to be practically instantaneous. Reactions between ions are, for example, practically instantaneous. Catalysis, of course, is not concerned with such reactions.

It is not strictly true that a catalyst is found to be *unchanged* at the end of a catalyzed reaction. It is correct to say that the final products are the same as they would have been had the catalyst been absent. The catalyst may be rather unmistakably changed, not in amount, but in physical state. Thus the crystalline manganese dioxide used to generate oxygen from potassium chlorate becomes a fine powder, and changes in physical state are known to occur in iron oxide and in platinum used as catalysts in other systems. The amount of the catalyst, no matter how small, seems to remain unchanged. Catalysts themselves may be accelerated or restrained in their rapidity of action. Two catalysts usually have a greater joint effect than either would have singly. "Promoters" that increase the activity of catalysts are also known. Some substances so completely obstruct the action of catalysts that they have been called "poisons." Enzymes and toxins have their poisons and antitoxins, and the analogy to them is quite close, even in the case of metallic catalysts. Some catalysts seem specific for a given reaction, but many are capable of manifold application, and no general method is known for guidance in selecting a catalyst for a given reaction.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

TYPICAL CASES OF THE DETERIORATION OF MUNTZ METAL (60-40 BRASS) BY SELECTIVE CORROSION.[1]

[ABSTRACT.]

BRASS of the type 60 copper and 40 zinc, which is used commercially in a variety of forms (*e.g.*, wrought bolts, sheathing, condenser tubes, extruded forms, etc.), often shows a kind of deterioration by which the metal changes its color to copper red and becomes very weak and brittle, although the shape and size apparently remain unchanged. This change of properties is due to a selective corrosion of the alloy, which has a duplex structure, when exposed to the action of some electrolyte, particularly sea-water. This type of corrosion has been recognized by manufacturers and users of brass for some time; the numerous samples illustrating this kind of deterioration which have been submitted to the Bureau of Standards, however, showed the utility of a description of typical cases of such corroded brasses. The study of such types includes bolts, boat sheathing, condenser tubes, and parts which were corroded while under stress.

The examination of the micro-structure shows clearly the method of the attack, the zinc-rich constituent being electrolytically "leached out," leaving a skeleton of weak pulverulent copper in its place, so that the piece becomes very weak and brittle. Later the second constituent may be attacked, so that the whole specimen is converted into pulverulent "copper"—the sample becoming so weak that it can be broken into fragments in the fingers.

Conditions which appear, from the examination of corroded samples, to accelerate this type of corrosive attack are: the micro-structural composition of the alloy, contact with strongly electronegative metals, the effect of certain adhering deposits of basic zinc chloride resulting from the corrosion, the thoroughness of the annealing the sample has previously received, the temperature of the electrolyte, and the stresses to which the specimens are subjected during the corrosive attack.

* Communicated by the Director.

[1] Technologic Paper No. 103.

AN INVESTIGATION OF THE AXIAL ABERRATIONS OF LENSES.[2]

[ABSTRACT.]

THE errors which affect the definition of a lens are discussed, and methods of graphically representing the central errors described. The condition for freedom from coma near the axis is arrived at. The relative importance of the errors in different types of lenses is discussed. Hartman's method is expanded, permitting one set of measurements to give all the important central errors—spherical aberration, zonal variation of equivalent focal length, axial and oblique achromatism. The apparatus and procedure are described, and the accuracy of the adjustments and the measurements discussed. The method is applicable to all systems of relatively short focus and large aperture, such as photographic lenses, projection lenses, and telescope objectives, and also to complete optical systems. The results of the method as applied to a complete telescope are discussed and shown to be independent of the accommodation of the observer. Seventeen sets of curves are given for as many different lenses, and an illustrative discussion of one set of curves, together with a general description of the types of lenses represented by each group of curves.

SOME ELECTRICAL PROPERTIES OF SILVER SULPHIDE.[3]

By George W. Vinal, Assistant Physicist.

[ABSTRACT.]

SILVER sulphide may be prepared in the form of short wires or thin strips like a metal. The wire, which must be drawn hot, was found to conduct electricity like a metal of high specific resistance and practically zero temperature coefficient. The strip of sulphide rolled at room temperature has a large temperature coefficient and shows both metallic and electrolytic conduction. It has a volt-ampère curve characteristic of a pyroelectric conductor. The strips are sensitive to small alternating currents, which increase the resistance enormously, while small direct currents have the opposite effect. The specific resistance has been measured and experiments made on the electrochemical decomposition.

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[2] Scientific Paper No. 311.
[3] Scientific Paper No. 310.

THE EFFECT OF THE SIZE OF GROG IN FIRE-CLAY BODIES.[4]

[ABSTRACT.]

The size of grain has long been known to exert considerable influence upon the properties of mortars, concrete, fire-clay refractories, and other materials. The present investigation determines the effect of the size of the calcined portion, or grog, upon the properties of fire-clay bodies within a field of practical sizes. The general plan of procedure consisted of separating grog into a number of sizes, recombining these in arbitrary proportions by calculation from triaxial diagrams, mixing with an equal weight of clay, and moulding with water into test pieces for the determination of various properties. Strength in the raw state, as indicated by the modulus of rupture, depended upon a number of factors and did not vary directly with the size of grog. Proper proportioning of grog sizes gave stronger bodies than single grog sizes. The strength of burned bodies increased directly with decrease of the size of grog, the size being expressed numerically as a surface factor. Bodies containing the larger sizes were more resistant to sudden heating and cooling from 600° C. and 1000° C. Volume shrinkage in burning to cone 12 increased approximately with decrease of porosity. No relation was found between strength and porosity in the dry or burned states. Methods are suggested for proper proportioning of grog for glass pots, saggers, and similar bodies.

WAVE-LENGTH MEASUREMENTS IN SPECTRA FROM 5600 A. TO 9600 A.[5]

By W. F. Meggers.

[ABSTRACT.]

Some work in spectroscopic analysis at the Bureau of Standards showed the importance of investigating the red and adjacent infra-red regions of spectra more carefully and extensively. Ordinary photographic plates were stained in a mixture of dicyanin, water, alcohol, and ammonia to make them sensitive to

[4] Technologic Paper No. 104.
[5] Scientific Paper No. 309.

the long light-waves. These stained plates were used to photograph the arc spectra of twenty of the chemical elements, including the alkali metals, the alkaline earths, and elements commonly found in iron as impurities. The photographs were made in the first order spectrum with a concave grating of 640 cm. radius, the grating being mounted in parallel light. This spectrograph gives a dispersion of about 10 A. per mm. in the first order. With this apparatus exposure times of 30 minutes sufficed to record waves longer than 9000 A. (A = Ångstrom = 0.0000001 mm.), and demonstrated the value of dicyanin as a photographic sensitizer for such spectral investigations. Waves which are 2000 A. longer than the longest waves in the visible spectrum were thus detected photographically without difficulty.

Accurate measurements of wave-lengths and determinations of the characteristics of the emission lines were obtained from these spectrograms. The second-order spectrum of the iron arc was photographed on either side of the first order, and the long wave-lengths were obtained from the standards in the iron spectrum. In this paper the wave-lengths in International Ångstroms are given for the arc spectra of the following elements: lithium, sodium, potassium, rubidium, cæsium, copper, calcium, strontium, barium, and magnesium.

Frequency differences of doublets in the spectra of sodium, potassium, rubidium, cæsium, and copper are shown by these wave-length measurements to be constant in most cases to one part in 100,000 in the number of waves per centimetre.

Comparison of the spectra made it possible to detect many impurities in the elements used for light-sources. Still more extensive spectral investigations are required in the region of long wave-lengths to identify all lines correctly.

THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, September 5, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 5, 1917.

VICE-PRESIDENT MR. LOUIS E. LEVY *in the Chair.*

The following report was presented for first reading:

No. 2702.—Austin Organ.

The following report was presented for final action:

No. 2694.—Lewis Machine Gun.

Recommended that the Elliott Cresson Medal be awarded to Col. Isaac Newton Lewis, of Montclair, N. J., for his invention of the Lewis Machine Gun.

GEO. A. HOADLEY,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 12, 1917.)

LIFE.

MR. A. ATWATER KENT, Manufacturer, Rosemont, Pa.

RESIDENT.

MR. FREDERICK M. BENNETT, Mechanical and Electrical Engineer, 112 West Pomona Street, Philadelphia, Pa.

DR. GEORGE L. KELLEY, Research Chemist, Midvale Steel Company, Philadelphia, Pa.

NON-RESIDENT.

MR. P. F. SMITH, JR., General Superintendent of Motive Power, Pennsylvania Lines West of Pittsburgh, Pennsylvania Station, Pittsburgh, Pa.

ASSOCIATE.

MR. ALAN I. APPELBAUM, Chemist, Import and By-Products Company, Trenton, N. J.

MR. CARL D. ULMER, Chemist, 408 Mellon Institute, Pittsburgh, Pa.

NECROLOGY.

Alois von Isakovics was born at Prague, Bohemia, on July 21, 1870, and died at Monticello, N. Y., on June 5, 1917. He was educated in Austria and graduated from the School of Chemistry of the University of Vienna.

In 1886 he came to the United States, and three years later established, in New York City, the widely-known Synfleur Scientific Laboratories for the synthetic production of perfumes. In 1903 the plant was removed to Monticello, N. Y.

Mr. Isakovics's occasional contributions to the technical press on subjects relating to perfumes, essential oils, and flavoring materials were read with interest by those engaged in similar fields of investigation and labor.

He was a member of the leading technical societies of the world, and his membership in The Franklin Institute dates from October 11, 1909.

Major Henry Souther, head of Aircraft Engineering Division, Signal Office, U. S. Army, died at the post hospital, Fort Monroe, on August 15.

He was born in Boston, Mass., on September 11, 1865. His early education was obtained in his native city, and his engineering training at the Massachusetts Institute of Technology, where he graduated in 1887.

Major Souther was engineer for the Pennsylvania Steel Company from 1888 to 1893, and the six years following he spent with the Pope Manufacturing Company, at Hartford, Conn.

He was president of the Souther Engineering Company, vice-president of the Standard Roller Bearing Company and of the Ferro Machine and Foundry Company. From 1899 to 1907 he served as Water Commissioner of Hartford, Conn.

Major Souther was called to Washington as consulting engineer of the Aviation Section of the Signal Corps in April, 1916, where he organized the inspection department. He was Director of the Langley Field, and conducted experimental tests of machines and engines. Major Souther was a member of numerous engineering and technical societies as well as social organizations.

The manuscript for his paper on "The Development and Progress in Aviation Motors," which appears in this issue, was finished only a short time before his last illness.

Mr. Virgil C. Bogue, 26 Courtlandt Street, New York City, N. Y.
Mr. R. S. Orr, Duquesne Light Company, Pittsburgh, Pa.
Mr. William F. Read, 209 Chestnut Street, Philadelphia, Pa.
Mr. Edwin Davis Tucker, 308 West 104th Street, New York City, N. Y.

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BOOK NOTICES.

EXPLOSIVES: THEIR MANUFACTURE, TESTS, PROPERTIES, AND HISTORY, by Arthur Marshall, A.C.G.I., F.I.C., F.C.S., Chemical Inspector, Indian Ordnance Department. Second edition. Philadelphia, P. Blakiston's Son & Company. 776 pages (total), contents and indices, illustrations, and several portrait plates. 2 volumes, large 8vo. Price, $16 net.

The early exhausting of the first edition of this work testifies to its excellence, a fact that we had occasion to note in the review of that edition. The enlargement has necessitated division into two volumes, which makes the book cumbersome, especially as heavy, coated paper is used, as was done in the first edition. There is really no necessity for such paper, which adds so much to the cost and weight of the book. Most of the illustrations could have been satisfactorily printed on lighter paper; moreover, many of them are too big. For instance, the picture of a section of armor-piercing shell, on page 559, would have shown the details just as clearly if it had been one-third its present dimensions.

The work is dedicated to Lloyd-George, whose picture appears as a frontispiece to one of the volumes, and who is at present, apparently, the real ruler of the British Empire, for if ever there was a time in English history of which it can be said that the "King reigns but does not govern," that time is now.

The reviewer can but repeat the commendations given in the review of the first edition. Mr. Marshall's extended practical experience enables him to present this important subject in all its aspects.

It was noted in the former review that no information is given in regard to the flash-powders so largely used in photography. These are nearly all very high explosives and well worth the careful consideration of experts in this field. An examination of the files of the *British Journal of Photography* and of the *English Mechanic* will bring to light many details of this class of "pyrotechnics" which have been the cause of much loss of life and property. The present edition, also, does not make any allusion to them, although a good deal of information is given concerning ordinary fireworks.

It is unfortunate that no advance has been made towards a scientific nomenclature. The same old forms, such as "glycerine," "acetate of lime," appear throughout. These phases of British non-progressiveness distress very much the American allies.

The work contains but few typographic errors; the structural formula of one of the dinitronaphthalenes (page 269) seems to be wrong, as it is designated as the beta-form, yet both nitro-groups are in the alpha-position. The statement is possibly taken from Thorpe (Dic. App. Chem., iii, 584), but does not accord with the orientation given in the same volume, page 563.

Mr. Marshall's work stands, at present, as the best exposition in English of the subject on which it treats.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Explosives, by Arthur Marshall. Second edition, vol. ii. Properties and Tests. 795 pages, illustrations, 8vo. Philadelphia, P. Blakiston's Son and Company, 1917. Price, $8.

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Konstant auftretende secundäre Maxima und Minima in dem jährlichen Verlauf der meteorologischen Erscheinungen XI. von Dr. E. van Rijckevorsel: Special Abzug aus Koninklijk Nederlandisch Meteorologisch Instituut, No. 102. Mededeelingen en Verhandelingen 22. 76 pages, illustrations, plates, 8vo. Utrecht, Kemin & Zoon, 1917.

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U. S. Bureau of Mines: Advanced First-aid Instructions for Miners. A report on standardization by a committee of surgeons. 154 pages, illustrations, 24mo. Bulletin 133, The Wet Thiogen Process for Recovering Sulphur from Sulphur Dioxide in Smelter Gases: a critical study by A. E. Wells. 66 pages, illustrations, plates, 8vo. Monthly Statement of Coal-mine Fatalities in the United States, May and June, 1917. 2 pamphlets, 8vo. Technical Paper 150, Limits of Complete Inflammability of Mixtures of Mine Gases and of Industrial Gases with Air, by George A. Burrell and Alfred W. Gauger. 11 pages, 8vo. Technical Paper 156, Carbon Monoxide Poisoning in the Steel Industry, by J. A. Watkins, 19 pages, illustrations, 8vo. Washington, Government Printing Office, 1917.

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CURRENT TOPICS

The Properties of Balsa Wood. R. C. CARPENTER. (*The American Society of Refrigerating Engineers' Journal*, vol. 3, No. 6, p. 30, May, 1917.)—The laboratories of Sibley College of Mechanical Engineering, Cornell University, have made an extended investigation of the properties of balsa wood for the purpose of ascertaining its physical properties. The wood is exceedingly light and promises to have an extensive field of usefulness in connection with cold storage structures where heat insulation is important. It is a tropical wood growing principally in the states of central and South America.

The wood is remarkable: first, as to its lightness; second, as to its microscopical structure; third, for its absence of woody fibre; fourth, for its elasticity; and, fifth, for its heat-insulating qualities. So far as the investigation has disclosed, it is the lightest commercial useful wood known. It has also considerable structural strength, which makes it suitable for many uses. In general appearance balsa wood resembles basswood. Until recently, Missouri cork wood, weighing 18.1 pounds per cubic foot, was believed to be the lightest, but recent investigations indicate that balsa wood is much lighter, having a weight of 7.3 pounds per cubic foot. The ordinary commercial balsa wood is seldom perfectly dry, and, because of the moisture content, its weight has been found to be between 8 and 13 pounds per cubic foot.

The extreme lightness of this wood suggests its application as a buoyancy material in life-preservers and lifeboats. When, however, it was attempted to apply the wood practically, it was found to be of little value, because it absorbed water in great quantities and also because it soon rotted and also warped and checked when worked. After testing nearly every method that had been suggested, Colonel Marr's method of treating woods which had been recently patented was finally successful. In this method the wood is treated in a bath, of which the principal ingredient is paraffin, by a process which coats the interior cells without clogging up the porous system. The paraffin remains as a coating or varnish over the interior cell walls, preventing the absorption of moisture and the ill-effects as to change of volume and decay which would otherwise take place; it also prevents the bad effects of dry rot which follow the application of any surface treatment for preserving wood of the same type. The Marr process tends to drive out all water and make the wood waterproof; it also improves its quality of being readily worked with tools without material increase in weight. The treated balsa wood has been used extensively in the manufacture of life-preservers, fenders for lifeboats, and for structures requiring insulation from heat, as in the refrigerating compartments of vessels and ice-boxes.

Tendencies in Bridge Construction. ANON. (*Engineering News-Record*, vol. 78, No. 11, p. 541, June 14, 1917.)—In the last 20 years the live loading of railway bridges has continuously increased. Every few years an increase takes place in bridge loads, and as often the opinion is expressed that the limit has been reached within existing clearances, or with the best locomotives that can be designed or with the available kinds of car wheels. When the Pennsylvania Railroad's Type R locomotive was believed to be a maximum for bridges, the loading might have been E-30, or even less. Many of those bridges are being replaced now, but they were fully loaded up to design capacity as much as 15 years ago. To-day live loading is in the region of E-60, and for a special bridge of the Bessemer and Lake Erie Railroad over the Allegheny River the live loading is on a basis of E-75. This, however, is a special bridge and is indicative of the maximum increment in loading rather than of the general average.

The Bessemer bridge, like the big Metropolis structure, is built of silicon steel, the newcomer in the company of nickel steel *et al.* Their use, so far, has been little more than a necessity in special cases, long spans and the like; they have had no influence on ordinary bridges. Stronger carbon steel than that used at present means a harder material; and harder metal than 60,000-pound bridge steel means drilling in place of punching. Present shops, as they are laid out and equipped, cannot drill any large tonnage, and punching must be depended upon, with the alternative of delay, trouble, and undue cost. Naturally, punching entails the use of tough, ductile steel.

As to truss types, the last 15 or 20 years have brought about little change, except for gradual extension of all-riveted construction and the recent use of k-webbing. The present tendency is toward simplifying trusses—using longer panels, simpler arrangements of bracing, and, wherever possible, eliminating subwebbing. In bridges of ordinary span it was the practice, not long ago, to make short panels—even 15 to 18 feet—where to-day 30 to 32 and 34-foot panels or longer are adopted. Among the several reasons for this, one is the reduction of secondary stresses, but more prominent is the effect of manufacturing advance and progress in erection appliances.

The widespread use of concrete construction has not in general influenced steel design. It is only in the development of concrete-floor types that it has effected changes in design. In bridges for certain classes of service concrete floors have practically supplanted trough floors. This refers particularly to bridges over streets in grade-crossing elimination and such structures. On truss railroad bridges there is little tendency at present toward solid floors, perhaps 95 per cent. is of the old standard open-tie construction. With longer panels coming into use, and, above all, the high impact that is always considered nowadays, the floor steel is a much more important element of the total weight, but this has no present effect

toward producing changes in truss design, though such an effect is bound to come in time.

With regard to the future development of continuous bridges, we have been going through a slow progression away from pin-connected design. Had the craze for pin bridges that prevailed a generation ago for a short period continued, we would not be ready for continuous spans; but, as it is, the present standard practice in truss details is entirely suited to continuous bridges, and at the same time we have outgrown any fears that may have existed formerly as to the certainty of stress calculations in continuous strucures. It was formerly believed that if the supports should settle even a trifle, the stresses would be very seriously changed. On that subject we have clearer notions nowadays. Every bridge engineer appreciates that, no matter how rigid a bridge, a long span is in fact quite flexible, and any minor settlement of a support, such as could occur in a normal case, would have only trifling influence on the stresses. Continuous bridges are surely going to be more used in the future.

Spontaneous Combustion. G. H. P. WALKER. (*National Fire Protection Association*, vol. ii, No. 1, p. 32, July, 1917.)—When we speak of spontaneous combustion we usually refer to that peculiar form wherein ignition takes place without evidence of the employment of any external agent. When ignition has taken place combustion follows the same laws, whether of spontaneous or other origin, and these laws always represent more or less complex chemical actions. Almost all chemical actions are attended with the liberation of considerable heat, and the quantity of heat set free is constant, whether the action be relatively slow, as in the decaying of a piece of wood, or whether it be rapid, as in the combustion of a similar piece of wood in a furnace, the products of combustion being identical in either case. Combustion, as we usually understand it, is the union of a substance with oxygen, but there are numerous instances where oxygen is not involved at all. The velocity of combustion increases with marvellous rapidity with rise of temperature, a rise of 200° F. increasing the velocity one thousand-fold.

Perhaps one of the commonest forms in which spontaneous combustion manifests itself is in the spontaneous ignition of a piece of cotton waste or an old rag saturated with oil and left lying in a warm place. Only certain oils possess the property of spontaneously igniting, and of these the most dangerous is linseed oil, the boiled variety being much worse than the raw, due to slight changes in its chemical structure which have been effected by the boiling, and due also to the presence of metallic salts (such as lead acetate, litharge, and manganese dioxide), which tend to accelerate the process of "drying" by acting as oxygen carriers. When spontaneous combustion results from an oil-soaked rag (or an oil mop, for instance) having been left carelessly in a warm room or in the sun, it is caused by the rapid oxidation of the oil spread out over the large surface

afforded by the folds of the cloth—the greater the exposed surface the more rapid the oxidation—and as the oil continues to combine with more and more oxygen from the air, the temperature gradually rises until sufficient heat has been developed to cause the mass to burst into flames. Mineral oils are not considered dangerous in this respect, and are sometimes added to quick-drying oils to lessen the danger of spontaneous ignition.

The reason why a can of linseed oil does not ignite when left uncovered is that the small surface exposed to the air cannot develop heat with sufficient rapidity to raise the whole body to the required temperature. Many other forms of spontaneous ignition occur, such as the ignition of finely divided particles of combustible substances suspended in the air, the oxidation of iron pyrites in soft coal, the slow oxidation of heaps of organic matter, as manure and hay and others. In all of these the surface-volume conditions play the important part in governing the relation of heat generation and dissipation upon which depends the rise in temperature.

The Artificial Silk Industry. L. P. WILSON. (*Journal of the Society of Chemical Industry*, vol. xxxvi, No. 14, p. 817, July 31, 1917.)—The material known as artificial silk, and sometimes wrongly described as imitation silk, is now in such general use for producing a large number of textile materials that there is no doubt whatever that, although the commercial production of artificial filaments is no older than this century, it has made for itself a permanent position in the world of industry. Artificial silk, once only suitable for fancy goods, more ornamental than useful, is now produced in filaments of almost unlimited length, of uniform diameter, and of any thickness from less than a thousandth of to a sixteenth of an inch, possessing any desired lustre, from the most brilliant to quite dull, capable of being dyed to any shade, and of sufficient tenacity, either dry or wet, to be used in any textile operation.

There was a period of one hundred and fifty years between the time of the suggestion of the French scientist, Réaumur, that silk might be made artificially from resins or similar materials and the date of the first patent, that of the Swiss, Andemars, for the production of artificial filaments, this latter having been made possible by the discovery and investigation of cellulose nitrate. From that time, about 1885, to the end of the century, a great deal of valuable preliminary work was done with the aim of producing artificial fibres for textile use or the production of electric lamp filaments. Among the British workers of note were Crookes, Wynne, Powell, Swinbourne, Swan, Millar, Cross, Topham, and Stearn, but they did not achieve commercial production during this period. On the Continent, however, Compte Hilaire de Chardonnet began to manufacture artificial silk in 1891, at the rate of 100 pounds per day, at Besançon, and, although

his success was not uninterrupted, he was producing about 4000 pounds per day before anything was made on an industrial scale by British workers.

All the early artificial silk was made by the Chardonnet process or modifications of it, which had for a basis gun-cotton dissolved in ether-alcohol. This solution was of very high viscosity and was formed into filaments by forcing it through glass jets with a bore between two and ten thousandths of an inch. These were immersed in water to remove the alcohol from the solution as it emerged, and so to form a solid fibre, which was picked up and with a number of others wound on a spool. On the Continent nitro silk had for some years great financial suecess, but at the beginning of this century it had to meet increased prices of raw materials and the competition of two other processes, cuprammonium and viscose.

The difficulties and defects of the processes of producing silk from nitro-cellulose led to much research after other methods and substances suitable for the production of artificial fibres, and the next process to be developed was that which made use of a solution of cellulose in ammoniacal copper oxide for spinning. A Frenchman, Despaissis, took out the first patent in this connection in 1890, but his early demise led to the lapsing of the patent until Pauly took out his first patent in Germany seven years later. Then followed a long series of patents which have been the basis of successful manufacture of the Vereinigte Glanzstoff Fabriken A. G. of Elberfeld, with subsidiaries in Austria, France, and Wales.

Viscose silk, the latest of the three important forms of artificial filaments to appear on the market in quantity, is the only one which is entirely English in its origin and development. Like the other artificial silks, it is a form of cellulose, but, unlike them, its starting material is not cotton but wood, and as it differs from them in its beginning, so it differs right through its stages of manufacture in processes and machinery, reactions and methods, until the final product is obtained. This also is distinguished from the others by its greater covering power and lustre, and its greater resistance to dyeing and finishing processes, and to wear. For these reasons it is thought by some competent to judge that, although its manufacture is more complicated than the older processes, it will ultimately supplant them. Cellulose xanthate, which forms the basis of the viscose silk process, was discovered by Cross, Bevan, and Beadle in 1892, and is formed by the interaction of cellulose, sodium, hydroxide, and carbon bisulphide. When dissolved in water or dilute caustic soda it forms a golden-brown thick syrup, and to this the discoverers gave the name viscose on account of its high viscosity.

The whole industrial history of artificial silk is embraced in the development of the nitro, cuprammonium, and viscose proc-

esses, but a number of other methods have been suggested and patented. The earliest, and at one time perhaps the most promising, because it was long successfully worked in the manufacture of electric lamp filaments, was the zinc chloride process; in spite of much work this has not been satisfactorily applied in the manufacture of artificial silk.

The Engineering Council. ANNOUNCEMENT. (I. N. Hollis and C. Townley, August, 1917.)—The formation of an Engineering Council is the outgrowth of a real need for proper consideration of questions of general interest to engineers and to the public, and to provide the means for united action upon questions of common concern. This war has brought out very impressively the actual need for united action of some kind. At present the Council is concerned with four societies, because that seemed the most practical way of getting a group of men together to answer immediate needs, but these societies do not assume to speak for all engineering societies in the country.

A now manifest need of enlargement may be effected by the union of all societies, either as the outgrowth of the present Council or by a congress of engineers leading to united action by all societies. We have three classes of engineers to reach: First, those who are members of local societies and not members of national societies; second, those who are members of national societies and not members of local societies; and, third, those who are not members of a society. The last-named class constitutes a very large number in our profession.

The four societies concerned at present are The American Society of Civil Engineers, The American Institute of Mining Engineers, The American Society of Mechanical Engineers, and The American Institute of Electrical Engineers. Many fruitful discussions have taken place leading to useful action, and many problems have already been presented before the Council. Certain questions, however, relate to the war and the assistance that engineers can render, and a committee, to be called the American Engineering Service Committee, was appointed with instructions to invite the coöperation of all engineering societies. Its present duty is the tabulation and listing of members of the five societies represented. This tabulation has already in part been done, but in a rather unsystematic and unequal way. It is hoped that the new committee, by having additions from other societies, may make a final and lasting tabulation of all the engineers in the United States. The list is to be kept in the Engineering Societies' Building for general use in government problems and in the industries. A great many engineers have already entered through the engineering societies, through colleges, and through various special boards in Washington. The importance, however, of a complete list of engineers and their professional specialties

cannot be overestimated, and such a complete list can only be made with the help of the local as well as of the national societies.

The office of the Council will be in the Engineering Building, 29 West Thirty-ninth Street, New York City.

Effect of Gas Lighting upon Ventilation. ANON. (*American Gas Engineering Journal*, vol. cvii, No. 8, p. 171, August 25, 1917.)—The assertion that gas lighting vitiates the atmosphere is often made, not because of a desire to unjustly condemn gas for illumination, but because of a conviction that the use of gas produced an alteration of the atmosphere which is harmful. Ordinary air is chemically defined as a mixture of the gases oxygen and nitrogen in the proportion of 20.7 per cent. by volume of oxygen and 79.3 per cent. by volume of nitrogen. The oxygen argument is one of the weapons which has been actively employed in creating the impression that the use of gas so decreases the oxygen content of the atmosphere that life is endangered. It is only when the oxygen content of the atmosphere is lowered below the region of 15 per cent. that signs of insufficient oxygen arise. Such a small reduction as about 1.5 per cent. under the worst possible conditions of ventilation has not the slightest effect upon health or comfort.

The sense of well-being depends very greatly upon the condition of the skin, and its ability to perform its functions. If the percentage of water vapor in the atmosphere is high, the evaporation from the body is greatly checked, but if the air is sufficiently removed from the saturation point, the functions of the body proceed as they should and health is unimpaired. Much of our comfort then depends upon temperature and humidity. The thermometer, however, is of very limited value in determining the comfort of the body, because it does not show the cooling effect of moving air or the change in cutaneous excitations produced by the variation in the strength of air currents. For estimating the physical conditions of the atmosphere we need an instrument to measure the rate of heat lost and not the average temperature.

Popular Lecture on Home Lighting. (*Bulletin Illuminating Engineering Society*, August, 30, 1917.)—The second of a series of popular lectures issued by the Illuminating Engineering Society is now ready for distribution. This lecture is devoted to the application of the fundamentals of home illumination. Some forty-five lantern slides accompany the lecture, which covers in detail and in an authoritative manner the specific requirements for home-lighting installations, combining the scientific, artistic, and psychological principles, but stating these requirements in a

non-technical paper of interest to popular audiences. The paper covers some twenty pages of reading matter and paragraphs descriptive of the lantern slides.

The lecture, with accompanying lantern slides, may be secured for presentation upon application to the general offices of the society, 29 West Thirty-ninth Street, New York City. Reservations should be made considerably in advance of the dates of presentation, as only a few sets of the lecture are available at this time. A small service charge covering the cost of upkeep and delivery is made for this lecture and for a similarly prepared lecture on "Store Lighting."

The Flow Meter and Its Relation to Plant Economy. J. H. HOUGH. (*General Electric Review*, vol. xx, No. 8, p. 649, August, 1917.)—The turbine and operating-rooms of the average power plant are provided with an up-to-date switchboard carrying every type of electrical instrument needful for the efficient distribution of power. By sharp contrast in the boiler-room, the fireman must struggle to hold the load on the boilers, with no guides to assist him but a pressure-gauge and a water column. The electric generators operating in parallel on the bus-bars are equipped with wattmeters to show exactly the load on each. The steam boilers operating in parallel on the main header are being operated blindly, with nothing to indicate in what manner they are dividing the load. The man who approves the coal bill does not stop to analyze the load efficiency curve of the boiler. He perhaps does not know that at one particular rating the best thermal efficiency is obtained, and that this efficiency drops rapidly when the boiler is very much below or above this point.

The big opportunity for reducing costs lies in the boiler-room. No one would expect the electrical end of the plant to be operated satisfactorily without some instruments to guide the operators. Yet the pressure-gauge and water column have been and are about all the average boiler attendant has to help him. For the rest, he is expected to be able to get along by using his eyes to judge the condition of the fire. There are some men naturally gifted who can do fairly well even under these circumstances, but the problem need not be left to human judgment when it can be easily simplified by providing a few thermometers, a steam flow meter, and a draft-gauge.

At the present time the flow meter finds its greatest field of usefulness on individual boiler units. It is the ammeter of the boiler. Various designs of the instrument have been brought out for this use, having its respective field of application. In one large plant the boilers are equipped with standardized indicating instruments to show the output of each unit at any instant in boiler horsepower. Changes of load affecting the efficiency are indicated and recorded, making it possible to govern the output of each boiler for the best efficiency.

Memorial to Joseph Priestley.—On July 31, 1874, many of the leading chemists of America met near the grave of Joseph Priestley, at Northumberland, to honor the memory of the man who had discovered oxygen one hundred years before. In an account of the proceedings detailed in the *American Chemist* for 1874 we are told that a movement was there begun which led later to the establishment of the American Chemical Society. As the foundation of the American Chemical Society has been thus linked with the name of Joseph Priestley, it would seem proper that his work as an investigator and philosopher and tireless searcher after truth should be commemorated in some lasting way.

To this end, the Council of the American Chemical Society adopted a resolution at its meeting in Urbana, in April, 1916, requesting the president to appoint a committee to devise and carry out a plan for a suitable memorial to Joseph Priestley. After careful consideration of various plans, the committee recommended: (1) That a bust portrait of Joseph Priestley be secured, to be a copy of the best available portrait; that this be retained as the property of the American Chemical Society, but be deposited as a loan to the National Museum in Washington. (2) That a gold medal be awarded at intervals of probably more than one year for superior achievement in chemical research; the award to carry with it the requirement that the recipient shall deliver an address before the general meeting of the society at the time of the presentation or at such other time and place as the Council may direct. Careful inquiry has convinced the committee that a fund of at least $2000 should be secured to carry out this plan. It is requested that subscriptions be sent to the chairman or any member of the committee. The committee is composed of fifteen members, of which Dr. F. C. Phillips, University of Pittsburgh, is chairman.

The United States Rifle, Model 1917. S. TRASK. (*Arms and the Man*, vol. lxii, No. 22, p. 429, August 25, 1917.)—Tried and tested, the performance of the new service rifle of the United States Army, officially designated "U. S. Rifle, Model 1917," has exceeded the most sanguine hopes of its sponsors. It is under this name that the British Enfield rifle of 1914 adapted to United States ammunition is known. Some apprehension was felt as to the trustworthiness of the new rifle, but fortunately the adaptation has now progressed to a point fully demonstrating that the change has been accomplished with due regard to the safety of those who will use the arm. The dimensions of the metal in the model of 1917 are equal to, and in some parts greater than, those in the Springfield. This strengthening has been principally over the receiver and at the butt of the barrel. In addition, the bolt of the new model is of nickel steel, and the re-

ceivers either of nickel or carbon steel. Facts of considerable interest concerning the model of 1917 and the arm from which it was adapted are gradually becoming known, and a statement from an officer who has given much time and study to the matter adds some illuminating details to the facts already known. He says:

"When the question of the desirability of obtaining a flatter trajectory with small arms was opened it was found that with the service 0.303 British rifle, known as the short Lee-Enfield, it was not possible to obtain as flat a trajectory as desirable, but a compromise was made and the Mark VII ammunition was introduced. This mark of ammunition differs from the Mark VI in the bullet having a sharper point and weighing 174 grains instead of 215 grains, the ballistics obtained in the short Lee-Enfield rifle being 2440 f/s. muzzle velocity with the cartridge heated to 60° for a maximum chamber pressure of 45,400 pounds per square inch. This ammunition gives a maximum height of trajectory of just under 9 feet for a range of 800 yards.

"It was obvious that the desired maximum height of trajectory of 5¼ feet for this range could not be obtained in the short Lee-Enfield rifle, and the question of the introduction of a new design of rifle was taken up. This led to the design of a rifle of 0.276 bore firing a rimless cartridge, and at the outbreak of the present war the trials had almost reached finality. One thousand of the rifles had been made and issued to troops for trial, and the design of the rifle was favorably reported upon. The ballistics given by this rifle were 2800 f/s. muzzle velocity for a chamber pressure of 51,500 pounds per square inch. The diameter of the base of the cartridge was 0.526 inch.

"When the war broke out, all question of re-arming had to be dropped. A large number of rifles, however, were required, and as no gauges for the short Lee-Enfield rifle were available, and as it was considered that the 0.276 rifle was of simpler design for manufacture and that re-arming would be taken up again at the conclusion of the war, some of the 0.276 rifles were sent to rifle manufacturers in this country to see if they could make rifles similar in design, but barrelled to take the British 0.303 Mark VII cartridge. This led to the introduction of the rifle magazine 0.303, Pattern 1914. This rifle only differs in design from the 0.276 rifle in the dimensions of the interior of the barrel, in the magazine arrangements, which had to be made suitable for a 'rimmed' cartridge, and the graduations of the sights.

"The diameter of the base of the Springfield cartridge being 0.473 inch against 0.526 inch, and the chamber pressure in the Springfield rifle with the cartridge of Model 1906 and in the 0.276 rifle being the same, it will be seen that the 0.276 rifle was designed to stand a greater thrust on the breech bolt and recoil surfaces than the Springfield rifle."

Immense Deposits of Potash Awaiting a Cheap Method of Extraction. ANON. (*U. S. Geological Survey Press Bulletin*, No. 333, September, 1917.)—The United States Geological Survey, Department of the Interior, has prepared a brief report on the deposits of greensand in the eastern part of the United States which contain potash. These deposits are immense beds of sand at or near the surface in New Jersey, Delaware, and other states on the Atlantic coast. They cover many square miles, are at some places as much as 30 feet thick, and carry locally a maximum of 7 per cent. of potash. The prospective value of these deposits at any place depends upon the quantity of greensand available and the ease with which it can be mined. Most of the deposits can be mined with a steam shovel or dredge.

Greensand usually consists of grains of glauconite, an insoluble silicate of potash, iron, and silica (which may contain 7 per cent. or more of potash), mixed with grains of quartz and other materials. It gradually decomposes on exposure to the weather, its potash being thus slowly rendered available for assimilation by plants. It has been used in the raw condition as fertilizer for over a hundred years, as much as 100,000 tons having been mined in a single year in New Jersey. However, though its use has proved profitable at places within easy hauling distance of the deposits, the freight rates prohibit a long haul of material containing so small a proportion of potash. The chemical and engineering problem is therefore to extract and concentrate the potash.

Experiments made by chemists and others give hope that some economical process of extraction will be found, and when a cheap process has been devised there will be an immediate demand for detailed information concerning the location, nature, and supply of greensand. In order to meet this expected demand the Survey has prepared this report.

According to the report, the best greensands are in New Jersey, running in a series of broad belts from Sandy Hook Bay southwestward across Monmouth, Ocean, Burlington, Camden, and Gloucester counties into Delaware, where they are abundant as far south as Middletown. Other less valuable deposits occur in Maryland, Virginia, North Carolina, Arkansas, and Texas, and probably other Southern States may contain similar deposits. The best of this sand will carry about 6.3 pounds of potash to the cubic foot, or about 75,000 tons for each square mile of sand one foot thick, or 1,500,000 tons for each square mile of a 20-foot bed. A bed of that thickness carrying 5 per cent. of potash should contain more than 1,000,000 tons of potash to the square mile and should also carry about 4,500,000 tons of iron and possibly 500,000 tons of phosphoric acid. To utilize these constituents is a problem in chemical engineering; to measure the raw material is the simpler problem in practical geology.

The paper also describes the methods of analysis of greensand, especially a new method worked out in connection with this study. It is published as United States Geological Survey Bulletin 660-B, "Notes on the Greensand Deposits of the Eastern United States," by George H. Ashley, and "Methods of Analysis of Greensand," by William B. Hicks and Reginald K. Bailey. The paper can be obtained free of charge by writing to the Director, United States Geological Survey, Washington, D. C.

Calcium Chloride. ANON. (*U. S. Geological Survey Press Bulletin*, No. 333, September, 1917.)—Calcium chloride is made from natural brines found in Michigan, Ohio, and West Virginia. As the same brines yield salt and bromine, practically every constituent in them is turned to profit. Calcium chloride is used as the circulating fluid in refrigerating plants, in cement concrete, and in automobile gas-engine water jackets to prevent freezing, and, on account of its power of absorbing moisture, for laying dust on roads, drying gases, vegetables and fruits, and dehydrating organic liquids. Calcium chloride in solution is especially valuable in automatic-sprinkler systems and in fire buckets.

According to the United States Geological Survey, Department of the Interior, the quantity of calcium chloride produced from natural brines and sold in the United States has recently been about 20,000 short tons a year, valued at $6 to $6.50 a ton. In 1916 the production from natural brines was 26,062 tons, valued at $216,729, the equivalent of $8.31 a ton.

Chromite, Important War Mineral. ANON. (*U. S. Geological Survey Press Bulletin*, No. 333, September, 1917.)—The importance of chromite as a war supply in the manufacture of armor plate, armor-piercing projectiles, stellite for high-speed tools, and automobile and other special steels can scarcely be overestimated, according to the United States Geological Survey, Department of the Interior.

The chief sources of supply for the United States during the last few years have been Rhodesia, New Caledonia, Turkey, and Greece, and the imports in 1916 were 114,655 long tons.

The greatly increased trade, especially in steel, and consequently larger demand for chromite have stimulated the search for it in the United States, as shown by the phenomenal increase in production, the amount sold in 1915 being only 255 tons, against more than 47,000 tons in 1916. In Maryland and Wyoming there has been only a small production, but in the Pacific coast states, especially California, the advance in the output has been remarkable. In Oregon the production was more than 3000 tons; in California it was nearly 44,000 tons. Not all of this was sold.

It is evident that for some time to come California will furnish the chief domestic supply. With a lively demand and good prices

bodies of ore farther from lines of transportation will be worked. The production from some deposits in 1917 is expected to exceed that of 1916.

An interesting feature of future chrome production lies in the fact that T. W. Gruetter has recently established at Kerby, Ore., a custom plant for concentrating black sand to win its gold and platinum. The black sand of the Klamath Mountains usually contains a considerable amount of chromite, and it is believed that by adding magnetic separators to Gruetter's plant to remove the other minerals from the tailings sufficient chromite may be obtained from the black sand in areas of chromiferous serpentine to make the operation financially successful. The process will evidently yield a high grade of chrome ore, which may be suitable for special uses.

There is considerable chromite in Cuba, but scarcely anything is known of its occurrence in Mexico or Central and South America.

Ferrochrome, the alloy used in making chrome steel, is now manufactured in the United States by electro-metallurgic methods, almost wholly in the East, at the plants of the Electro Metallurgical Company at Niagara Falls and elsewhere. It is reported, however, that the Noble Electric Steel Company has three furnaces at Heroult, Calif., operating to their full capacity in producing manganese, chrome, and silica steels.

Prospecting for chromite may disclose other supplies, and the most profitable deposits will be those in areas of serpentine that are adjacent to cheap rail or water transportation or connected with it by good roads. Cheap concentration may in places improve the grade of the ore available for profitable mining.

With the known supplies of chromite and others whose discovery within the limit of practicable transportation throughout the United States is confidently expected, there is good reason to believe that the domestic output of chromite could be so increased as to go far toward supplying the domestic demand if our imports, except those from Canada, were cut off.

The Purple Color of Lamp Globes. M. LUCKIESH. (*General Electric Review*, vol. xx, No. 8, p. 671, August, 1917.)—The purplish tint of lamp globes is commonly observed. Glasses exposed to sunlight and to X-rays sometimes undergo a similar change. It is generally assumed that this color is due to a change in the chemical or physical state of the manganese which is present in most clear glasses. This coloration of glasses under exposure of radiant energy is not alone confined to glasses containing manganese. Sometimes glasses containing potash, but free from manganese, gradually assume a bluish tinge, and those containing sodium a yellowish-green tinge. Spectral analyses

show conclusively that the purple coloring is due to manganese. This color is quite unstable, for it disappears under the moderate heat of the Bunsen flame long before the glass is sufficiently hot to lose its rigidity. Manganese in clear glass performs the primary function of neutralizing the greenish tint usually present owing to slight quantities of iron oxide in the ingredients of the mix.

The spectral transmission of a glass containing a slight amount of iron is approximately complementary to that of a glass containing a slight amount of manganese; that is, the purple of the manganese neutralizes the green of the iron. This, however, is done at the expense of light transmission. An example will make the process clear. Suppose the slight amount of iron present reduced the transmission factor by 5 per cent., and that in order to neutralize this color a sufficient amount of manganese must be incorporated to reduce the transmission factor by 6 per cent. Without considering surface reflection, the total transmission loss becomes 11 per cent., and the only return for this loss is a neutralization of the slightly greenish tint.

Besides this initial decrease there is often a gradual decrease in the transmission factor as the purple color is brought out by the intense radiation from the sun and artificial light sources. Measurements show that when this color is noticeable to casual observation the transmission factor has been reduced from 10 to 25 per cent. Pieces of arc lamp globes have shown transmission factors of slightly more than one-half, and other specimens in which the purple color was quite pronounced have shown a loss varying from 55 to 85 per cent. A remedy for such losses is to eliminate manganese and accept the greenish tint with its higher transmission factor.

Lamp with Renewable Filament. ANON. (*Electrical World*, vol. 70, No. 9, p. 410, September 1, 1917.)—An incandescent lamp which can be readily recharged with gas and fitted with a new filament is disclosed in patent No. 1,232,741, issued to A. J. West, of Winnipeg, Manitoba. In this lamp, which is of the gas-filled type, there is no need for a vacuum, as it is only necessary to retain the gas in the globe under its own pressure. Accordingly the lamp is so made that the globe can be removed to permit the renewal of the filament, and when the globe is attached to the head the joint is tight enough to retain the gas admitted. Further, in the head is provided an easy means for refilling the lamp with gas and retaining the gas.

Upon the filament being rendered useless the globe can readily be unscrewed from the head and the filament withdrawn through the neck of the globe. After a new filament has been substituted the globe can be replaced. At this time, however, it

is necessary to recharge the globe with gas. This is done by removing a screw plug and recharging the globe with gas through a provided opening. Upon the globe being filled with the gas it is screwed tightly in and the plug is inserted.

Bibliography of the Literature of Submarines, Mines, and Torpedoes. D. B. RUSHMORE, W. H. LANMAN, and E. A. LOF. (*General Electric Review,* vol. xx, No. 8, August, 1917.)—At the present moment there is a widespread desire for knowledge on the subject of submarines, the information concerning which is widely separated and is difficult of location and access. Little has been known by the public in general on this subject, partly because of its apparent relative unimportance, and partly because much of the activities concerning these boats has been considered confidential and the subject somewhat shrouded in secrecy. The enormous losses sustained by the successful tactics of this type of craft have made the problem of finding a means of overcoming this menace paramount to all else.

With a view to making as accessible as possible available sources of information that may be of some assistance in solving this problem of the hour, a considerable effort has been made to gather in this issue of the *Review* a bibliography on submarines and allied subjects covering the period between 1873 and 1917. A list of patents on the same subjects dated from 1850 to the present is also given. Among the books mentioned, by far the best historical treatise to be had is the "Evolution of the Submarine Boat, Mine, and Torpedo," by Commander Murray F. Suetter, of the Royal Navy, published in 1908. A more recent work of a somewhat popular nature, but containing much valuable information, is "Submarines, Their Mechanism and Operation," by Frederick A. Talbot.

The Aluminum Air-cooled Cylinder. ANON. (*The Autocar,* vol. xxxix, No. 1137, p. 105, August 4, 1917.)—One great advantage of aluminum, apart from its light weight, is the high heat conductivity of this metal, and, as compared with cast iron and steel, it is of great advantage in an air-cooled engine, where efficient cooling entirely depends upon the rapidity with which heat is conducted by the cylinder metal from its source to the atmosphere. At the temperature at which conductivity comparisons are usually made, copper has nearly twice the value of aluminum, and aluminum five times that of iron. That there are real possibilities for the air-cooled engine is indicated by the successful performance of the Franklin car, which is giving continued satisfaction to its users.

In the recent Frontenac racing car, aluminum enters largely in the engine construction, this metal being used for the cylinder block castings, among other important parts. One way and

another, it seems very difficult to avoid the subject of aluminum for engine construction, because, even if we demand water cooling as the only fully satisfactory method for motor-cars, we shall not evade the question of aluminum cylinders with cast-iron liners. The saving in weight between aluminum cylinders with liners and cast-iron cylinders and jackets is so much in favor of aluminum that those who disbelieve in it will have to establish some compromise by adopting a lighter system of jacketing than can ever be achieved in cast iron. In this there will be no novelty, as the sheet-metal water jackets surrounding iron cylinders are very old in motor construction, and at one time almost all the best continental machines had these jackets. In all probability they would not have been abandoned had the earlier methods of getting water-tight joints for these jackets been so successful as those adopted at a later period.

Cracking Hydrocarbon Vapors by Electricity. ANON. (*Electrical World*, vol. 70, No. 7, p. 295, August 18, 1917.)—A process that aims to obtain by means of an electric discharge a greater yield of fixed gases from hydrocarbon vapors is the development of J. G. Davidson and R. W. Ford, of Vancouver, B. C., Canada. Patent No. 1,229,042 has been granted covering the discovery that by passing such vapors through an electric brush discharge field the amount of noncondensible gases is increased. In actual tests it is claimed that by this process the amount of CH_4 in the gas has been increased from about 25 per cent. to approximately 40 per cent., while the amounts of C_nH_{2n} were increased from between 7 per cent. to 10 per cent. to between 20 per cent. and 23 per cent. Ordinarily the gas is conducted through a plurality of conduits formed as vertical pipes, connected at their lower ends to a supply header and at their upper ends to an outlet header, the discharge electrode being formed as wires hung axially in the pipes from an insulated support. The pipes are grounded and the electrodes are connected by a wire to a mechanical rectifier of the usual rotary type included in the high-tension circuit of a step-up transformer, the rectifier connected to ground.

Marking Materials. L. B. BAKER. (*Scientific American*, vol. cxvii, No. 11, p. 195, September 15, 1917.)—If a diamond be drawn across a piece of glass, its path is marked by a scratch, the deepness of which depends upon the amount of pressure exerted in the operation. This scratch, as we all know, is an actual rupture or tearing of the surface of the glass. Again, if a piece of lead be rubbed over a rough surface of steel a mark is made which, contrary to the conditions in the previous example, is composed of the marking material. Finally, if a liquid or semi-liquid composed of dye or coloring matters in suspension, or chemicals capable of reacting to produce color, be placed on a smooth surface and allowed to dry, we have

the production of a kind of marking different from that in either of the above examples.

At first sight all three of these methods seem extremely simple in principle; and, indeed, the use of a hard writing object upon a material softer than itself, or the application of dyes and colors, does not offer many perplexing problems for the physicist to explain. But the use of a material which by friction leaves on the writing surface a mark composed of its own substance is not quite so simple. In the first place, disregarding all writing materials which may be made of a sticky composition, it is extremely difficult, if not impossible, to write upon a hard surface, if that surface be smooth or polished. Evidently, then, one of the prerequisites is a writing surface to a greater or less degree rough.

A consideration of equal importance is the nature of the writing substance itself. This must possess the quality of yielding up very minute particles of itself when it is being drawn across the uneven surface of the material written upon. That all soft substances do not possess this property will be evident if an ordinary rubber eraser, appreciably soft to the touch, be drawn over a rough surface of steel. It leaves a mark far less visible than that produced under the same conditions of application by a piece of lead, far harder to the touch than the rubber. Many similar examples might easily be quoted; even in the case of the ordinary pencil, we are familiar with the apparent greater hardness of the graphite core of the pencil as compared with the paper.

A closer examination will disclose the fact that the property really essential to a successful marking material concerns itself with the quantity of coherence existing between the minute particles of the substance, and the relative ease or difficulty with which they detach themselves from each other under the action of abrasion. For instance, the individual particles which go to make up the structure of a diamond are extremely hard themselves, and they are united to each other so strongly that ordinary abrasion on no known substance has the power to tear them apart. On the contrary, the core of a pencil is composed of a material the small individual units of which, although harder to the touch than the paper, are so loosely bound together that the abrasion caused by writing detaches them from their mass.

Under the microscope the surface of ordinary paper is seen to be very rough. The various fibres of which the sheet is made appear on the surface as a tangle of thread-like strands. Because these fibres are more or less rounded in cross-section they are slight depressions or pockets between adjacent fibres. It is these pockets which fill up with the pencil substance and make what we all recognize as the pencil mark. The pencil mark is not a continuous black line, but consists almost entirely of isolated pockets, as described above, each containing a little deposit of graphite. Furthermore, very little mark, if any, is left upon the fibre itself.

The Pyrogenesis of Hydrocarbons. E. L. LOMAX. (*Journal Institution of Petroleum Technologists*, 1916, through *Journal Industrial and Engineering Chemistry*, vol. 9, p. 879, 1917.)—The products of the pyrogenetic treatment of petroleum may be divided into four general classes; namely, permanent gas, illuminating oils, aromatic hydrocarbons, and volatile fuels for internal-combustion engines. These classes also represent, roughly, the lines on which development has taken place. Although the manufacture of permanent gas is of secondary importance in petroleum technology, the earliest work on the pyrogenesis of petroleum was started with that end in view.

The use of illuminating gas made from oil was proposed as early as 1792 by Murdock, and in 1805, as well as in 1821. Henry described the gas obtained by cracking animal oils, fats, and waxes, noticing the formation of ethylene. Between these two dates, John Dalton carried out the first scientific investigation on the pyrogenetic decomposition of hydrocarbons by subjecting ethylene and methane to the action of electric sparks. It is evident that about this time the question of the production of gas from oil occupied the attention of inventors and scientists, for in 1825 we have the classic discovery of benzene by Faraday. The brilliant researches of Berthelot in 1866–1867 on the action of heat upon various hydrocarbons also mark an important epoch in the development of the subject. The results of this work stand to the present day, the whole study being worthy of the great author.

The attention of the oil industry was directed to the question of increased production of illuminating oils by "cracking," an operation that was accidentally discovered in 1861, owing to the carelessness of a stillman who built a strong fire under his still and left it running, intending to return in about an hour. He did not, however, return till about four hours later, when he found the still running a light-colored distillate of lower specific gravity than that which was passing when he left. Experiment showed that a portion of the distillate had condensed upon the upper cooler part of the still and, dropping back upon the hot residue, was decomposed into lower-boiling constituents. This discovery had, however, to some extent been anticipated by Silliman in 1855, who advanced the theory that several of the products of distillation of petroleum were results of heat and chemical change during distillation. The discovery led to a large amount of technical and scientific work on increasing the production from petroleum of illuminating oil, which at that time was the most valuable product obtained.

In the early investigations catalytic action was ignored, but at more recent dates great attention has been given to the value of catalysts, finely divided metals and their compounds being employed. Notable among these is the use of metallic halides, in which field the well-known reaction of Friedel and Crafts has formed the basis for a number of experiments on the decomposition

of hydrocarbons. Aluminum chloride has generally been employed.

The demand for volatile hydrocarbons for use as fuel in internal-combustion engines in late years, and the question of obtaining an increased production by the utilization of fractions of crude petroleum of otherwise less value, have stimulated the activities of engineers and chemists in finding a solution to the problem. Prominent among recent developments are the processes of Rittman and Hall. The Rittman process for the manufacture of gasolin and benzene-toluene from petroleum and other hydrocarbons has been extensively exploited in the United States, the investigations which led to this discovery and its large-scale development having been carried on under the direct auspices of the United States Bureau of Mines.

It has long been known that aromatic hydrocarbons can be produced from certain types of petroleum, a process having been patented as early as 1860 for the recovery of oil-gas made from petroleum, but Rittman claims that it has never before been demonstrated that they can be produced in any considerable quantities from any type of oil. In the early part of 1915, however, they were being produced by the Hall process, which if not prior to the Rittman process was at least abreast with it. The benzene-toluene spirit produced by the Rittman process contains considerable quantities of non-aromatic bodies unattacked by strong sulphuric acid, and for the production of trinitrotoluene from the toluene fraction special methods have to be devised. The spirit produced by the Hall process, on the other hand, contains only minute traces of non-aromatic bodies unattacked by strong sulphuric acid, and the toluene produced is as easily nitrated as coal-tar toluene. The cost of the installation appears almost prohibitive. The cost of a plant on the Rittman benzene-toluene process handling about 18,000 gallons of oil per day would be $335,000. With the Hall process a plant capable of handling 10,000 gallons of oil per day would cost about $58,000.

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